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Preliminary Observations Regarding LDV Scans of Panels Excited by Broadband Actuators at the U.S. Capitol

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14. ABSTRACT

Experiments were conducted on frescos and wall paintings at the U.S. Capitol Building in order to determine the effectiveness of an electromagnetic shaker-based approach of evaluating the condition of the substructure. A scanning laser Doppler vibrometer (LDV) was used to measure the vibratory response of the work of art subjected to the shaker excitation. This report contains a representative sample of the data obtained on two panels as well as a short synopsis of several observations and conclusions made regarding this data. Processed velocity data, in conjunction with data derived from traditional methodologies, indicate that the shaker-based LDV approach is an effective method for the efficient mapping of areas of structural deficiencies in need of amelioration by a conservation engineer.

15. SUBJECT TERMS

Scanning laser Doppler vibrometry; Frescos; Wall Paintings; Brumidi plaster degradation; Non-destructive evaluation

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PRELIMINARY OBSERVATIONS REGARDING LDV SCANS OF PANELS EXCITED BY BROADBAND ACTUATORS AT THE US CAPITOL

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INTRODUCTION

The United States Capitol has large expanses of important fine art and decorative paintins executed directly on the original lime plaster. These paintings, which are invaluable for historical and aesthetic reasons, cannot be separated from the plaster without extreme risk. This has necessitated that the integrity of the supporting structures be evaluated in-situ so that degradations underlying the artwork can be located and repaired. In support of an on-going restoration and preservation program in the building, the authors were invited to demonstrate and evaluate one of their new concepts for non-destructive evaluation of the integrity of such structures on several panels in the Brumidi Corridor in the Senate Wing of the United States Capitol.

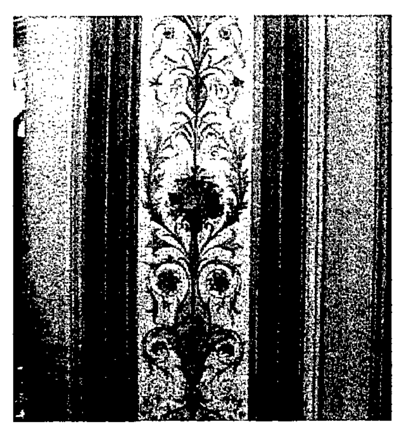

Figure 1 – "Pineapple" Panel

The following represents a short synopsis of several observations we have made regarding measurements made at the U.S. Capitol using a scanning LDV to map normal velocity of two panels when each was excited at one point by a broadband force actuator. The panels are identified as 6W1S (panel 1) and 6S1W (panel 2), the latter being what is called a pilaster. Regarding panel integrity, Panel 1 is

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characterized as simple in the sense that tapping tests indicate defect areas that involve less than 10% of the total panel area. Panel 2, on the other hand, is more complex in that at least 50% of the panel area appears to have some defects. The scan density was every three cm for panel 1 and every one cm for panel 2.

PANEL 1

We first discuss the measurements taken on Panel 1 (see Fig. 1). Simple sequential observations (see Figs. 2a - 2g and Figs. 3a - 3f) of the velocity scans (phase and amplitude) at each three Hertz increment indicate that we have obtained meaningful data on panel 1 over the band from about 80Hz to 1KHz. From 80Hz to about 400 Hz we can observe what appears to be simple wave propagation from the lower left corner where the actuator is located up toward the upper right hand corner. This seems especially clear from the phase plots. The wave speed is very crudely estimated to be about 700 m/sec over this lower band, suggesting shear wave propagation in the plaster. Beginning just below 400 Hz one can see even higher motions over a smaller patch size (about 18cm by 26 cm) near the right edge just above the scanned panel center. It appears strongest at about 460 Hz and seems to fade in and out with something like a 25-40 Hz period. At about 670 Hz, the motion over this patch breaks into a two-lobe mode pattern. Both the extent and location of this mobile patch coincides with a defect area discovered earlier in the tap test data. We should point out, however, that the same tap test data seems to indicate another defect area on the left, a location where we do not see any obvious localized high levels of motion in the LDV maps in this frequency band.

An attempt was made to combine the individual narrow-band scans into a broadband map. We did this by forming the sum over the frequency bands of the properly normalized quantity **|VV*|** at each spatial point. The resulting maps are shown in Figs. 4a - 4c for the full band and two partial bands, respectively. In addition to the dominant mobile patch in the upper right previously discussed, there appears to be additional larger areas with levels lower by some 30dB. As can be seen in Figs. 4b and 4c, these seem to be dependent on frequency. At this point, we are not certain whether these broader features are actually related to increased mobility of the structure or a signal to noise related artifact.

PANEL 2

Figure 5 – "Eagle" Panel

Panel 2 (Fig. 5) is on what is known as a pilaster, a segment of the wall that protrudes rectangularly from the wall. Observation of the velocity phase plots (see Figs. 6a - 6l) indicates that we have obtained meaningful data on this panel 2 from about 500Hz to 6KHz. Generally, what appeared as simple wave motion (shear) in panel 1 can be seen again in the panel 2 data up to about 1KHz. However, the higher frequency panel 2 data which is available beyond 1 KHz begins to look more modal in character. However, the spatial mode structure still seems to be related to shear wavenumbers. As in panel 1, at the lower frequencies (below about 1KHz) a local patch with high mobility is readily seen against the long wavelength wave motion. However, as frequency is increased, it becomes more difficult to notice such regions because of the modal-like structure of the base panel motion. However, at some frequencies it is still possible to do so when the local patch motion reaches high enough velocity levels. This is the case, for example, at around 800Hz and 980Hz where a high mobility patch can be observed just in from the left panel edge at the vertical midline; between about 860Hz and 930Hz where both this patch and another below and just to the left of it can be seen; at about 1070 Hz, 1200 Hz, and 1290 Hz where in addition a second patch near the top can be seen; at about 1400Hz, 1500Hz, 1800Hz where this upper patch becomes isolated; and at five or so frequencies above 5 kHz where only a new, highly localized patch (about 2cm in extent) can be seen in the lower quadrant just right of the panel center. It may be fortuitous, but we can make a simple comparison between this result and that for the mobile patch seen in panel 1. In particular, the panel 1 patch is about 20cm in extent and first appears (resonates) at 420Hz whereas the panel 2 high frequency patch first appears at about 5.2 KHz and is about 2cm in extent. The ratio of the two frequencies is 12 which is close to the inverse ratio of their spatial sizes (10). This relationship would be expected for the resonance of two patches having identical thicknesses but different lateral extent.

In Figs. 7a - 7c is shown the normalized **|VV*|** quantity for three different bands at frequencies below 2KHz. The above mentioned features for these frequencies now appear even more pronounced, presumably due to the frequency

averaging (and thus smearing) of the background modal structure of the panel. There also now appear three other mobile patches, one at the panel center, one below that point near the bottom, and one just below and to the right of the second patch from the left. Finally in Fig. 8 is shown the normalized **|VV*|** quantity for the entire band, 770Hz to 5KHz. Here all of the above features can be seen. This figure seems to indicate a total defect area of about 30-40%, a number consistent with the 50% level estimated with the tap tests. In addition, the broadband motion now clearly reveals two vertical discontinuities, the sharpness of which suggests they are connected to the structural design of the panel.

POST PROCESSING

In the following, we present the result of applying several post-processing algorithms to the LDV data. In Fig. 9 we show the results of applying a 1-D Fourier spatial transform on the velocity data over the band 10Hz to 8KHz. This used the data along a vertical line about 20cm from the left edge of panel 2. Imposed on the figure is the dispersion line for a vertical shear wave traveling in the plaster at a speed of about 700m/s. One can see significant energy out to this shear line indicating that our earlier speculation of predominate shear wave propagation even at the higher frequencies is correct.

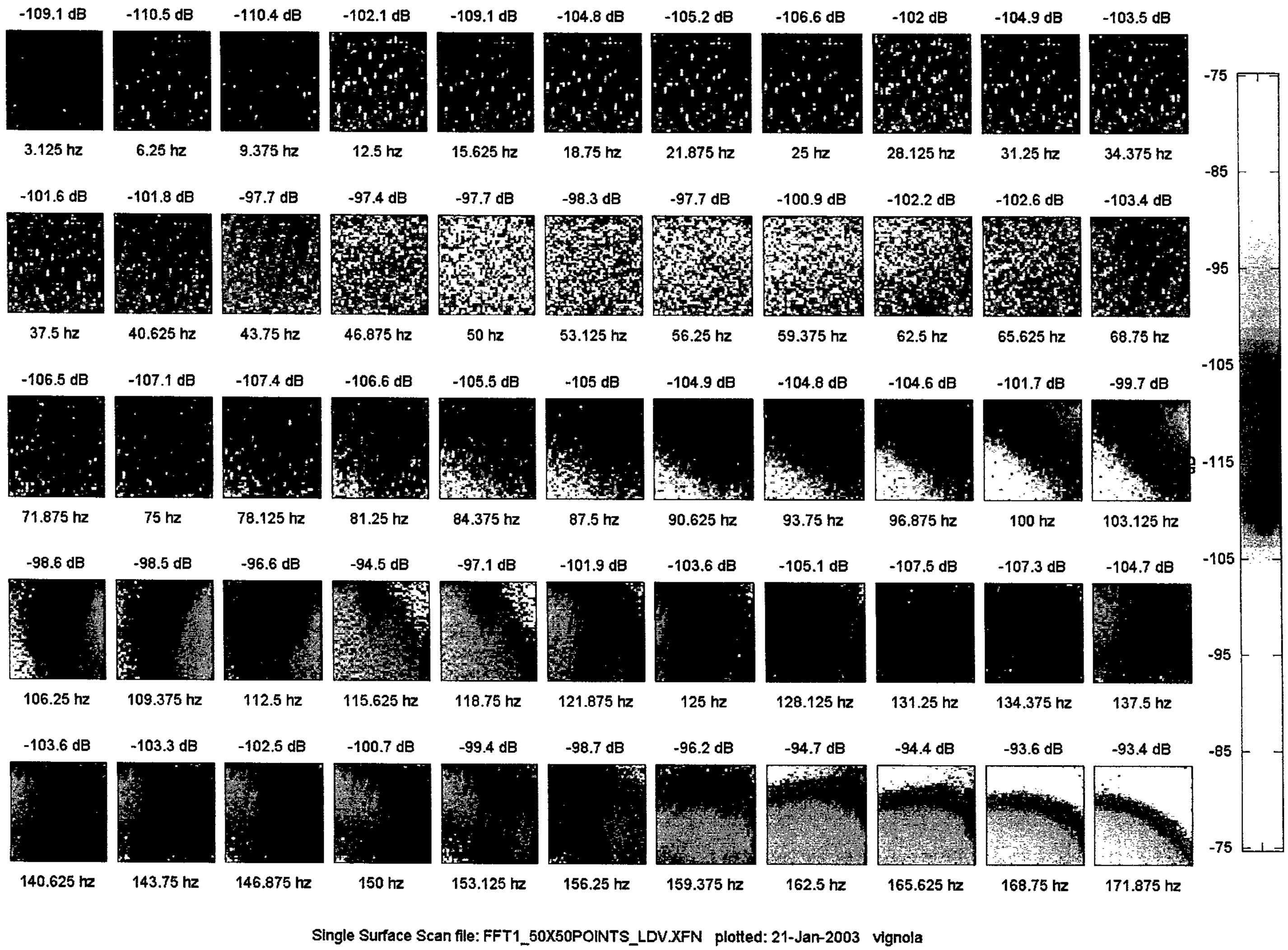
We also considered the application of a cross-correlation algorithm which we have used for another application. In this approach, the LDV measured velocity at each point ($\vec{r}$) is multiplied by the complex conjugate of that at a reference point ($\vec{r}'$). The function would be of the form $|V(\vec{r})V^*(\vec{r}')|$. For panel 2, we show in Fig. 10 this quantity for one particular $\vec{r}'$ for the band 770 Hz to 1500 Hz. This should be compared to Fig. 7a, which is a special case of the function above, namely the autocorrelation function, i.e. when $\vec{r} = \vec{r}'$. In our experience, the cross correlation algorithm can, in some cases, extract low-lying features missed by the autocorrelation approach.

Finally, we attempted to invert the LDV measured velocity field to obtain a map of the elastic modulus using an algorithm we have developed based on the equations of motion. The mapping resulting from the inversion is shown in Fig. 11. Based upon our experience in applying this algorithm, we believe the strong red features are artifacts resulting from operating our wave-based algorithm on a modally-excited structure. We believe, however, that the deep blue feature on the

left is real and indicates that this patch has a stiffness roughly one half that of the overall panel.

CONCLUSIONS

The results discussed above for panel 1 and panel 2 suggest that LDV scans of panels excited locally with a broadband actuator can provide important information about the layered panel integrity. One can also intuit that it would be beneficial to collect such data for more than one local actuator position. This seems prudent since in general one cannot be certain that any particular local actuation scheme will result in elastic energy distributed more or less uniformly throughout the panel.



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-110.5 dB
-110.4 dB
-102.1 dB
-109.1 dB
-104.8 dB
-105.2 dB
-106.6 dB
-102 dB
-104.9 dB
-103.5 dB
3.125 hz
6.25 hz
9.375 hz
12.5 hz
15.625 hz
18.75 hz
21.875 hz
25 hz
28.125 hz
31.25 hz
34.375 hz
-101.6 dB
-101.8 dB
-97.7 dB
-97.4 dB
-97.7 dB
-98.3 dB
-97.7 dB
-100.9 dB
-102.2 dB
-102.6 dB
-103.4 dB
37.5 hz
40.625 hz
43.75 hz
46.875 hz
50 hz
53.125 hz
56.25 hz
59.375 hz
62.5 hz
65.625 hz
68.75 hz
-106.5 dB
-107.1 dB
-107.4 dB
-106.6 dB
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-101.7 dB
-99.7 dB
71.875 hz
75 hz
78.125 hz
81.25 hz
84.375 hz
87.5 hz
90.625 hz
93.75 hz
96.875 hz
100 hz
103.125 hz
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-98.5 dB
-96.6 dB
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-97.1 dB
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-105.1 dB
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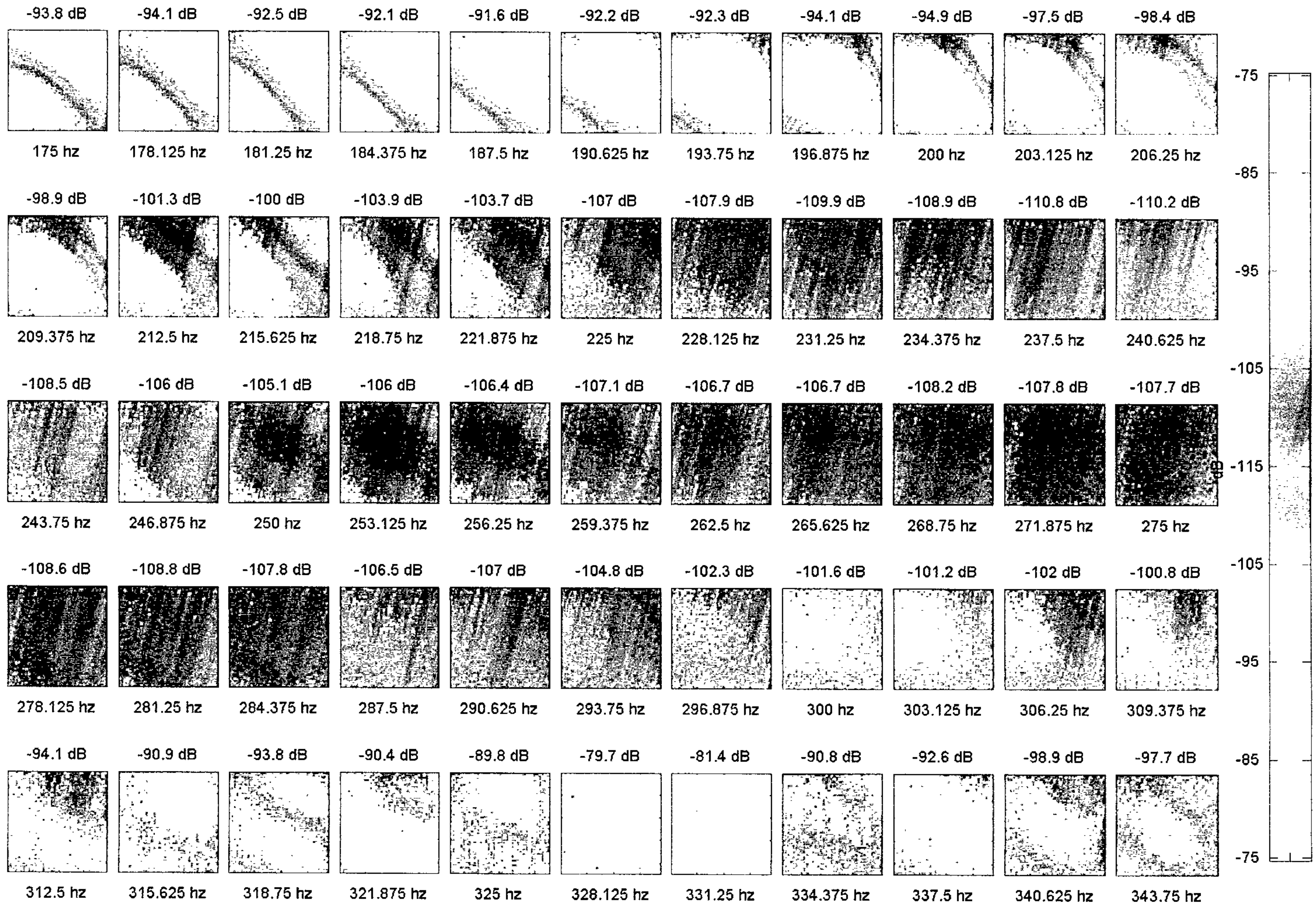
-104.7 dB
106.25 hz
109.375 hz
112.5 hz
115.625 hz
118.75 hz
121.875 hz
125 hz
128.125 hz
131.25 hz
134.375 hz
137.5 hz
-103.6 dB
-103.3 dB
-102.5 dB
-100.7 dB
-99.4 dB
-98.7 dB
-96.2 dB
-94.7 dB
-94.4 dB
-93.6 dB
-93.4 dB
140.625 hz
143.75 hz
146.875 hz
150 hz
153.125 hz
156.25 hz
159.375 hz
162.5 hz
165.625 hz
168.75 hz
171.875 hz
-75
-85
-95
-105
-115
-105
-95
-85
-75
Single Surface Scan file: FFT1_50X50POINTS_LDV.XFN plotted: 21-Jan-2003 vignola

Figure 2a

Panel 6W1S



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Panel 6W1S

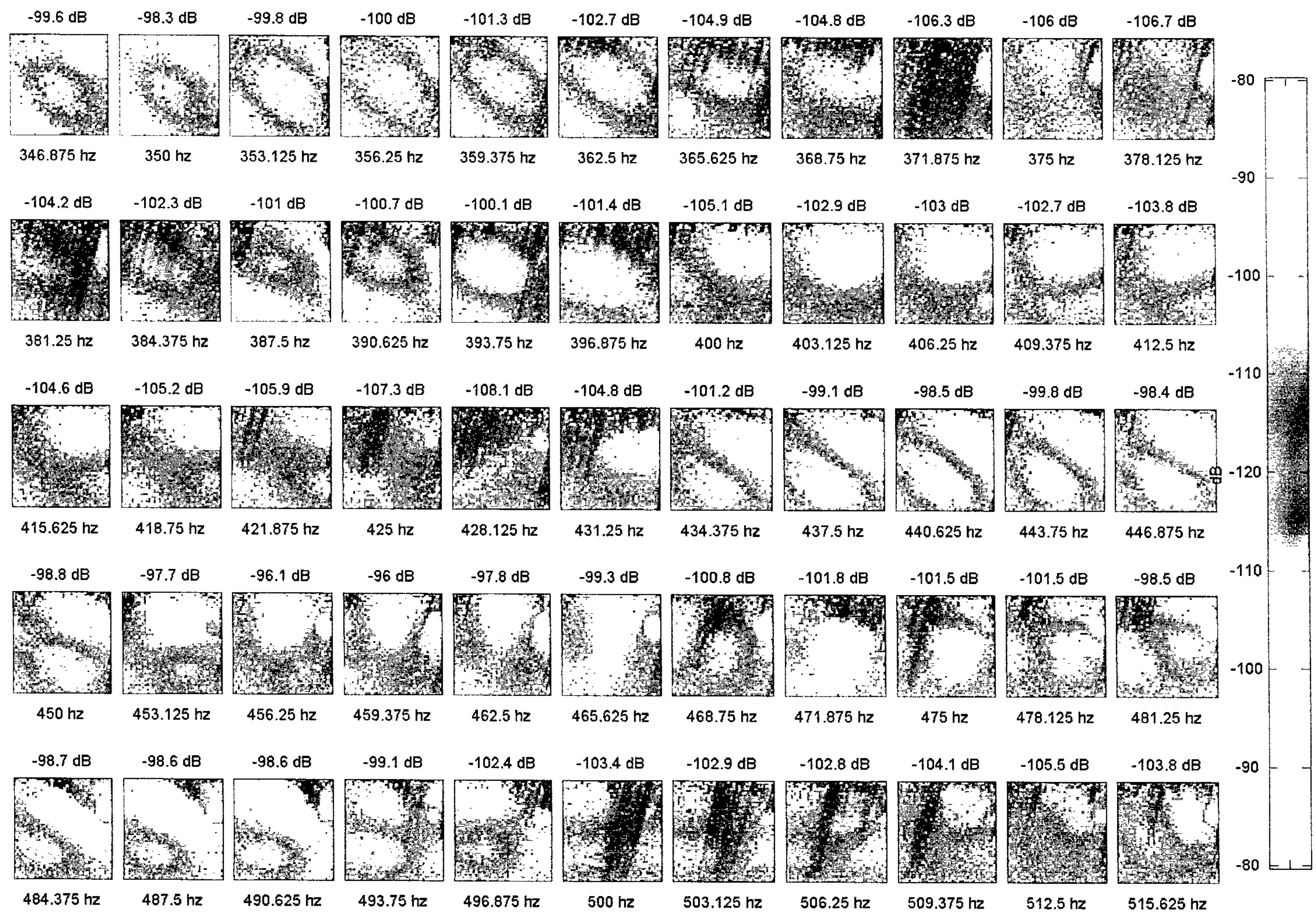

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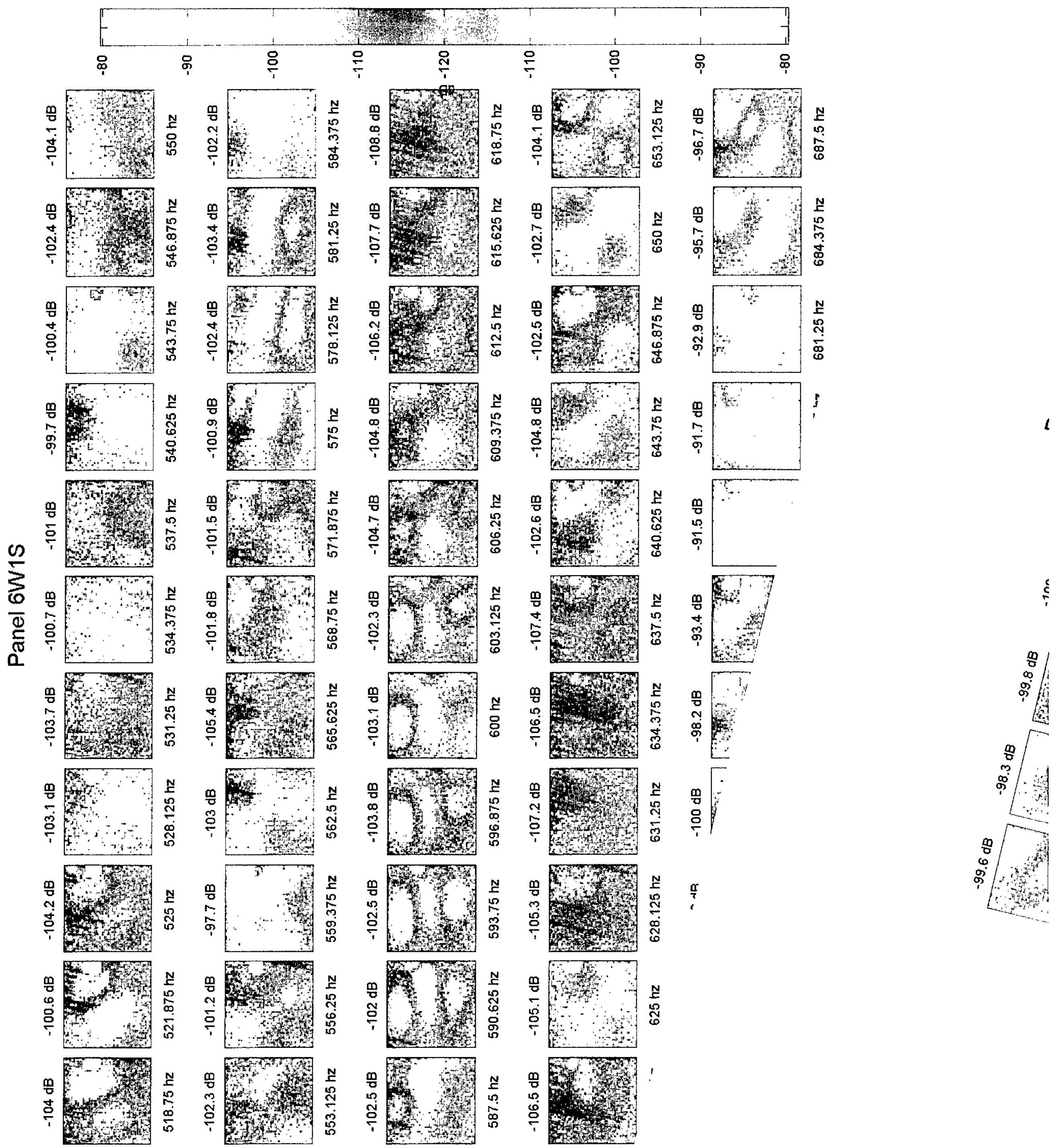
Figure 2c



Panel 6W1S
-80
-90
-100
-110
-120
-110
-100
-90
-80
dB
-104 dB
518.75 hz
-100.6 dB
521.875 hz
-104.2 dB
525 hz
-103.1 dB
528.125 hz
-103.7 dB
531.25 hz
-100.7 dB
534.375 hz
-101 dB
537.5 hz
-99.7 dB
540.625 hz
-100.4 dB
543.75 hz
-102.4 dB
546.875 hz
-104.1 dB
550 hz
-102.3 dB
553.125 hz
-101.2 dB
556.25 hz
-97.7 dB
559.375 hz
-103 dB
562.5 hz
-105.4 dB
565.625 hz
-101.8 dB
568.75 hz
-101.5 dB
571.875 hz
-100.9 dB
575 hz
-102.4 dB
578.125 hz
-103.4 dB
581.25 hz
-102.2 dB
584.375 hz
-102.5 dB
587.5 hz
-102 dB
590.625 hz
-102.5 dB
593.75 hz
-103.8 dB
596.875 hz
-103.1 dB
600 hz
-102.3 dB
603.125 hz
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606.25 hz
-104.8 dB
609.375 hz
-106.2 dB
612.5 hz
-107.7 dB
615.625 hz
-108.8 dB
618.75 hz
-106.5 dB
-105.1 dB
625 hz
-105.3 dB
628.125 hz
-107.2 dB
631.25 hz
-106.5 dB
634.375 hz
-107.4 dB
637.5 hz
-102.6 dB
640.625 hz
-104.8 dB
643.75 hz
-102.5 dB
646.875 hz
-102.7 dB
650 hz
-104.1 dB
653.125 hz
-100 dB
-98.2 dB
-93.4 dB
-91.5 dB
-91.7 dB
-92.9 dB
681.25 hz
-95.7 dB
684.375 hz
-96.7 dB
687.5 hz
-99.6 dB
-98.3 dB
-99.8 dB


Panel 6W1S
-99.2 dB
690.625 hz
-100.6 dB
693.75 hz
-100.3 dB
696.875 hz
-98.9 dB
700 hz
-99 dB
703.125 hz
-100.1 dB
706.25 hz
-100.4 dB
709.375 hz
-101.1 dB
712.5 hz
-100.9 dB
715.625 hz
-104.4 dB
718.75 hz
-107.4 dB
721.875 hz
-105.5 dB
725 hz
-105 dB
728.125 hz
-106.3 dB
731.25 hz
-106.3 dB
734.375 hz
-106.6 dB
737.5 hz
-106.7 dB
740.625 hz
-107 dB
743.75 hz
-107.6 dB
746.875 hz
-107.5 dB
750 hz
-105.7 dB
753.125 hz
-106.8 dB
756.25 hz
-108.1 dB
759.375 hz
-107.8 dB
762.5 hz
-107.9 dB
765.625 hz
-107.9 dB
768.75 hz
-107.3 dB
771.875 hz
-108.2 dB
775 hz
-108.6 dB
778.125 hz
-105.6 dB
781.25 hz
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-107 dB
787.5 hz
-104.4 dB
790.625 hz
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793.75 hz
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825 hz
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840.625 hz
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846.875 hz
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850 hz
-104 dB
853.125 hz
-105.6 dB
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-90
-100
-110
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dB
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-100
-90
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Figure 2e

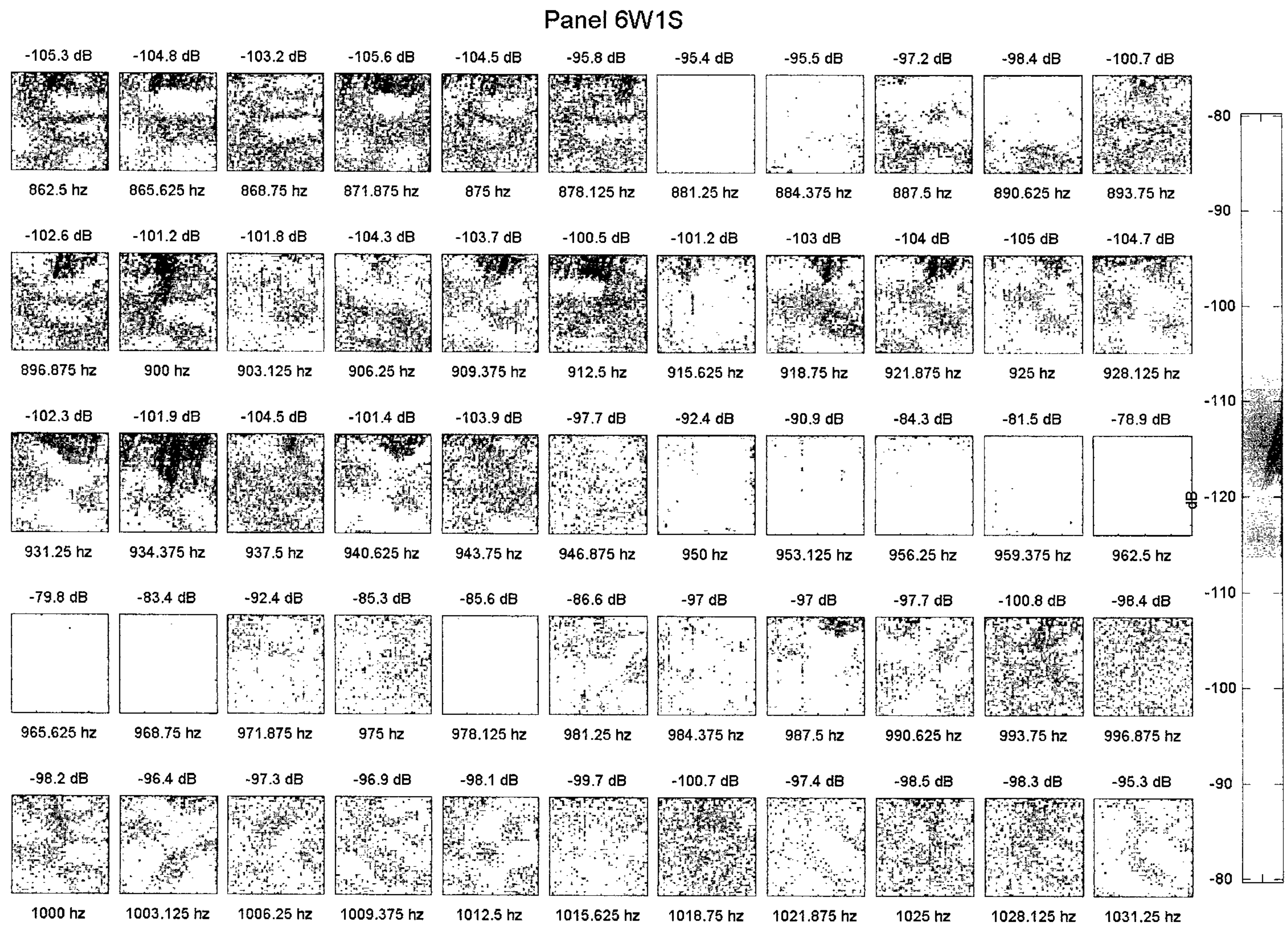

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Figure 2f

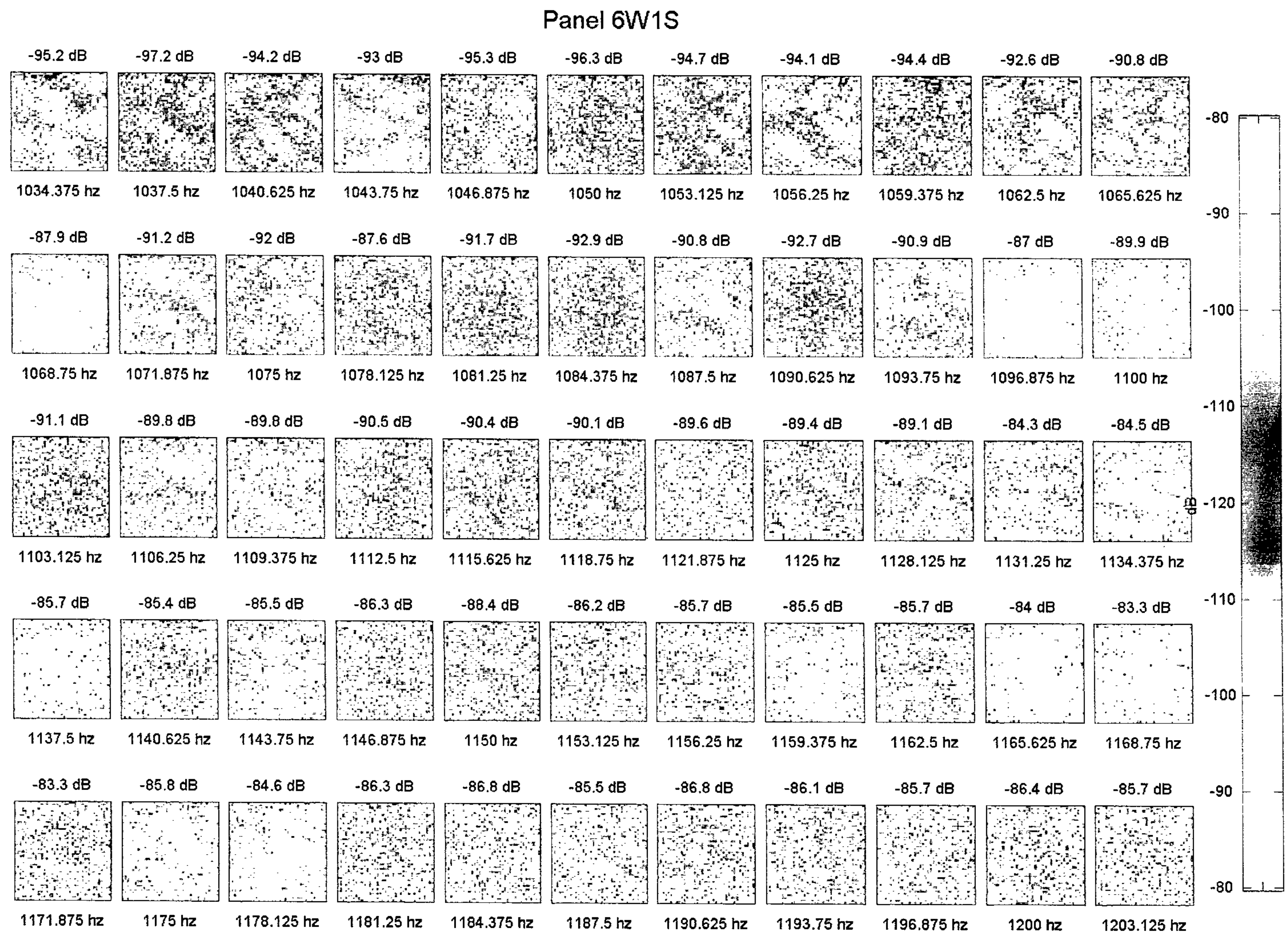

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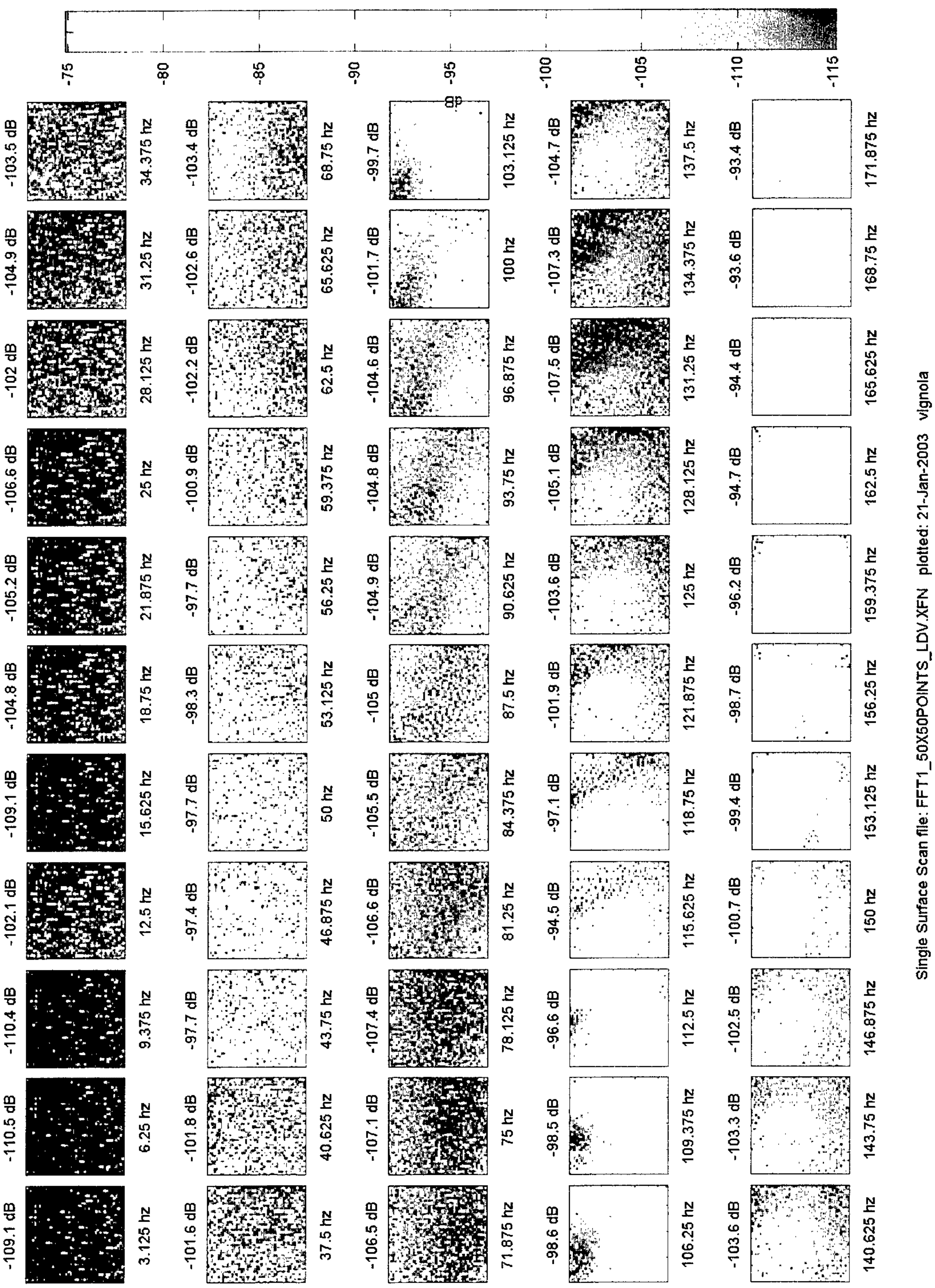
Figure 2g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12.5 hz
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15.625 hz
-104.8 dB
18.75 hz
-105.2 dB
21.875 hz
-106.6 dB
25 hz
-102 dB
28.125 hz
-104.9 dB
31.25 hz
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34.375 hz
-101.6 dB
37.5 hz
-101.8 dB
40.625 hz
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43.75 hz
-97.4 dB
46.875 hz
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50 hz
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56.25 hz
-100.9 dB
59.375 hz
-102.2 dB
62.5 hz
-102.6 dB
65.625 hz
-103.4 dB
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71.875 hz
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75 hz
-107.4 dB
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-106.6 dB
81.25 hz
-105.5 dB
84.375 hz
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93.75 hz
-104.6 dB
96.875 hz
-101.7 dB
100 hz
-99.7 dB
103.125 hz
-98.6 dB
106.25 hz
-98.5 dB
109.375 hz
-96.6 dB
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118.75 hz
-101.9 dB
121.875 hz
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-75
-80
-85
-90
-95
dB
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-105
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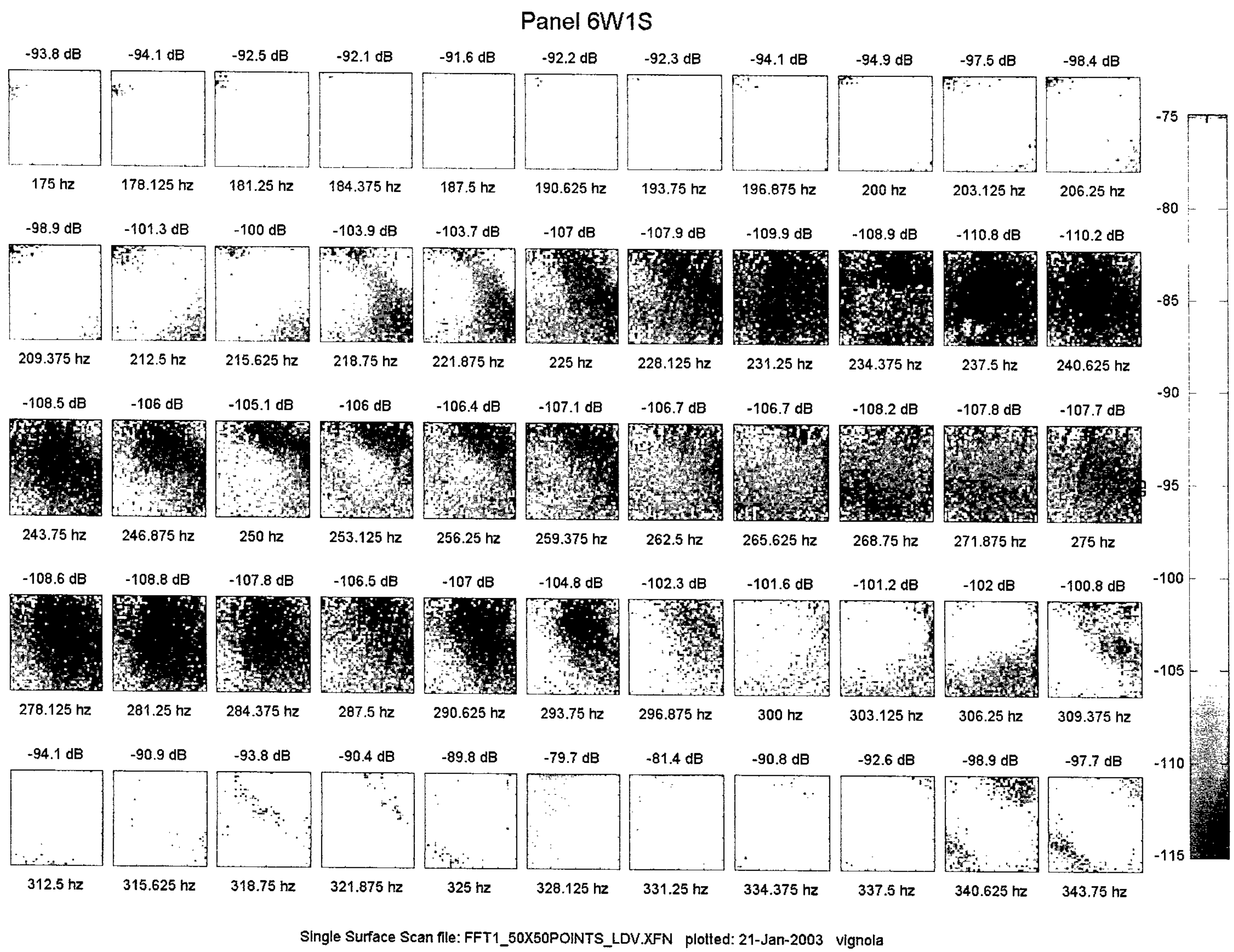
Figure 3a


Panel 6W1S
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175 hz
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190.625 hz
-92.3 dB
193.75 hz
-94.1 dB
196.875 hz
-94.9 dB
200 hz
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-101.3 dB
212.5 hz
-100 dB
215.625 hz
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259.375 hz
-106.7 dB
262.5 hz
-106.7 dB
265.625 hz
-108.2 dB
268.75 hz
-107.8 dB
271.875 hz
-107.7 dB
275 hz
-108.6 dB
278.125 hz
-108.8 dB
281.25 hz
-107.8 dB
284.375 hz
-106.5 dB
287.5 hz
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328.125 hz
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331.25 hz
-90.8 dB
334.375 hz
-92.6 dB
337.5 hz
-98.9 dB
340.625 hz
-97.7 dB
343.75 hz
-75
-80
-85
-90
-95
-100
-105
-110
-115
Single Surface Scan file: FFT1_50X50POINTS_LDV.XFN plotted: 21-Jan-2003 vignola

Figure 3b

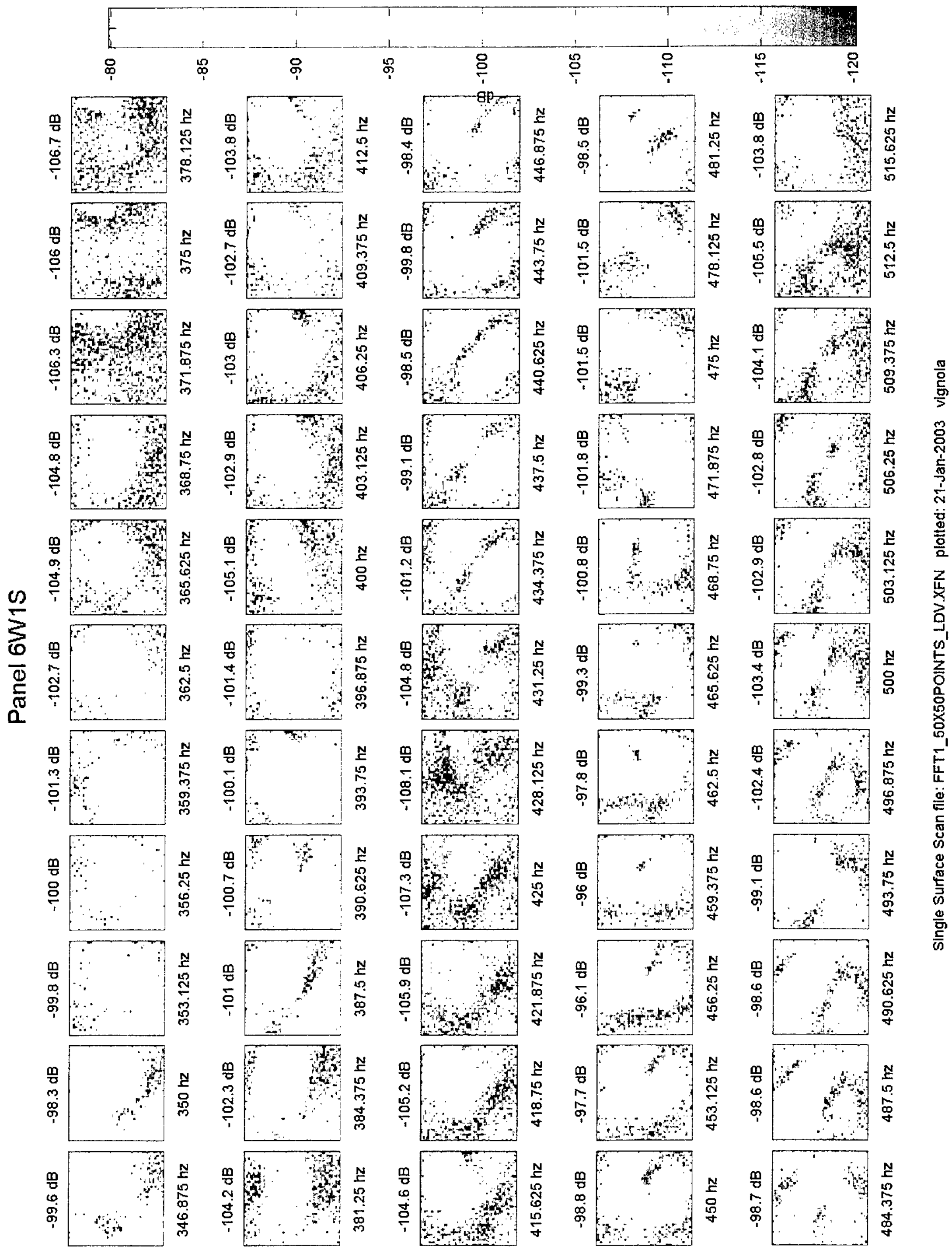

Panel 6W1S
-99.6 dB
346.875 hz
-98.3 dB
350 hz
-99.8 dB
353.125 hz
-100 dB
356.25 hz
-101.3 dB
359.375 hz
-102.7 dB
362.5 hz
-104.9 dB
365.625 hz
-104.8 dB
368.75 hz
-106.3 dB
371.875 hz
-106 dB
375 hz
-106.7 dB
378.125 hz
-104.2 dB
381.25 hz
-102.3 dB
384.375 hz
-101 dB
387.5 hz
-100.7 dB
390.625 hz
-100.1 dB
393.75 hz
-101.4 dB
396.875 hz
-105.1 dB
400 hz
-102.9 dB
403.125 hz
-103 dB
406.25 hz
-102.7 dB
409.375 hz
-103.8 dB
412.5 hz
-104.6 dB
415.625 hz
-105.2 dB
418.75 hz
-105.9 dB
421.875 hz
-107.3 dB
425 hz
-108.1 dB
428.125 hz
-104.8 dB
431.25 hz
-101.2 dB
434.375 hz
-99.1 dB
437.5 hz
-98.5 dB
440.625 hz
-99.8 dB
443.75 hz
-98.4 dB
446.875 hz
-98.8 dB
450 hz
-97.7 dB
453.125 hz
-96.1 dB
456.25 hz
-96 dB
459.375 hz
-97.8 dB
462.5 hz
-99.3 dB
465.625 hz
-100.8 dB
468.75 hz
-101.8 dB
471.875 hz
-101.5 dB
475 hz
-101.5 dB
478.125 hz
-98.5 dB
481.25 hz
-98.7 dB
484.375 hz
-98.6 dB
487.5 hz
-98.6 dB
490.625 hz
-99.1 dB
493.75 hz
-102.4 dB
496.875 hz
-103.4 dB
500 hz
-102.9 dB
503.125 hz
-102.8 dB
506.25 hz
-104.1 dB
509.375 hz
-105.5 dB
512.5 hz
-103.8 dB
515.625 hz
-80
-85
-90
-95
-100
-105
-110
-115
-120
dB
Single Surface Scan file: FFT1_50X50POINTS_LDV.XFN plotted: 21-Jan-2003 vignola

Figure 3c

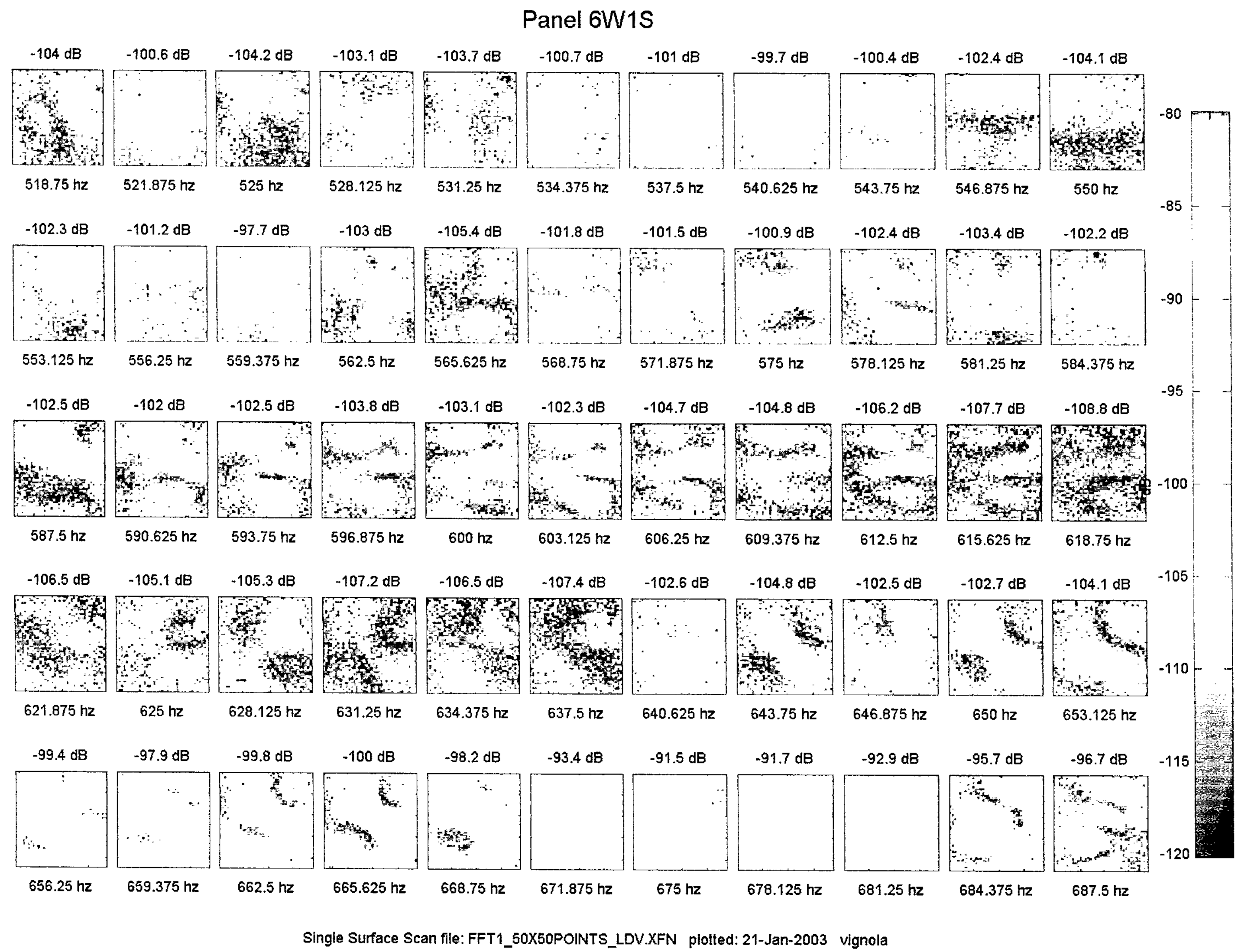

Panel 6W1S
-104 dB
518.75 hz
-100.6 dB
521.875 hz
-104.2 dB
525 hz
-103.1 dB
528.125 hz
-103.7 dB
531.25 hz
-100.7 dB
534.375 hz
-101 dB
537.5 hz
-99.7 dB
540.625 hz
-100.4 dB
543.75 hz
-102.4 dB
546.875 hz
-104.1 dB
550 hz
-102.3 dB
553.125 hz
-101.2 dB
556.25 hz
-97.7 dB
559.375 hz
-103 dB
562.5 hz
-105.4 dB
565.625 hz
-101.8 dB
568.75 hz
-101.5 dB
571.875 hz
-100.9 dB
575 hz
-102.4 dB
578.125 hz
-103.4 dB
581.25 hz
-102.2 dB
584.375 hz
-102.5 dB
587.5 hz
-102 dB
590.625 hz
-102.5 dB
593.75 hz
-103.8 dB
596.875 hz
-103.1 dB
600 hz
-102.3 dB
603.125 hz
-104.7 dB
606.25 hz
-104.8 dB
609.375 hz
-106.2 dB
612.5 hz
-107.7 dB
615.625 hz
-108.8 dB
618.75 hz
-106.5 dB
621.875 hz
-105.1 dB
625 hz
-105.3 dB
628.125 hz
-107.2 dB
631.25 hz
-106.5 dB
634.375 hz
-107.4 dB
637.5 hz
-102.6 dB
640.625 hz
-104.8 dB
643.75 hz
-102.5 dB
646.875 hz
-102.7 dB
650 hz
-104.1 dB
653.125 hz
-99.4 dB
656.25 hz
-97.9 dB
659.375 hz
-99.8 dB
662.5 hz
-100 dB
665.625 hz
-98.2 dB
668.75 hz
-93.4 dB
671.875 hz
-91.5 dB
675 hz
-91.7 dB
678.125 hz
-92.9 dB
681.25 hz
-95.7 dB
684.375 hz
-96.7 dB
687.5 hz
-80
-85
-90
-95
-100
-105
-110
-115
-120
Single Surface Scan file: FFT1_50X50POINTS_LDV.XFN plotted: 21-Jan-2003 vignola

Figure 3d

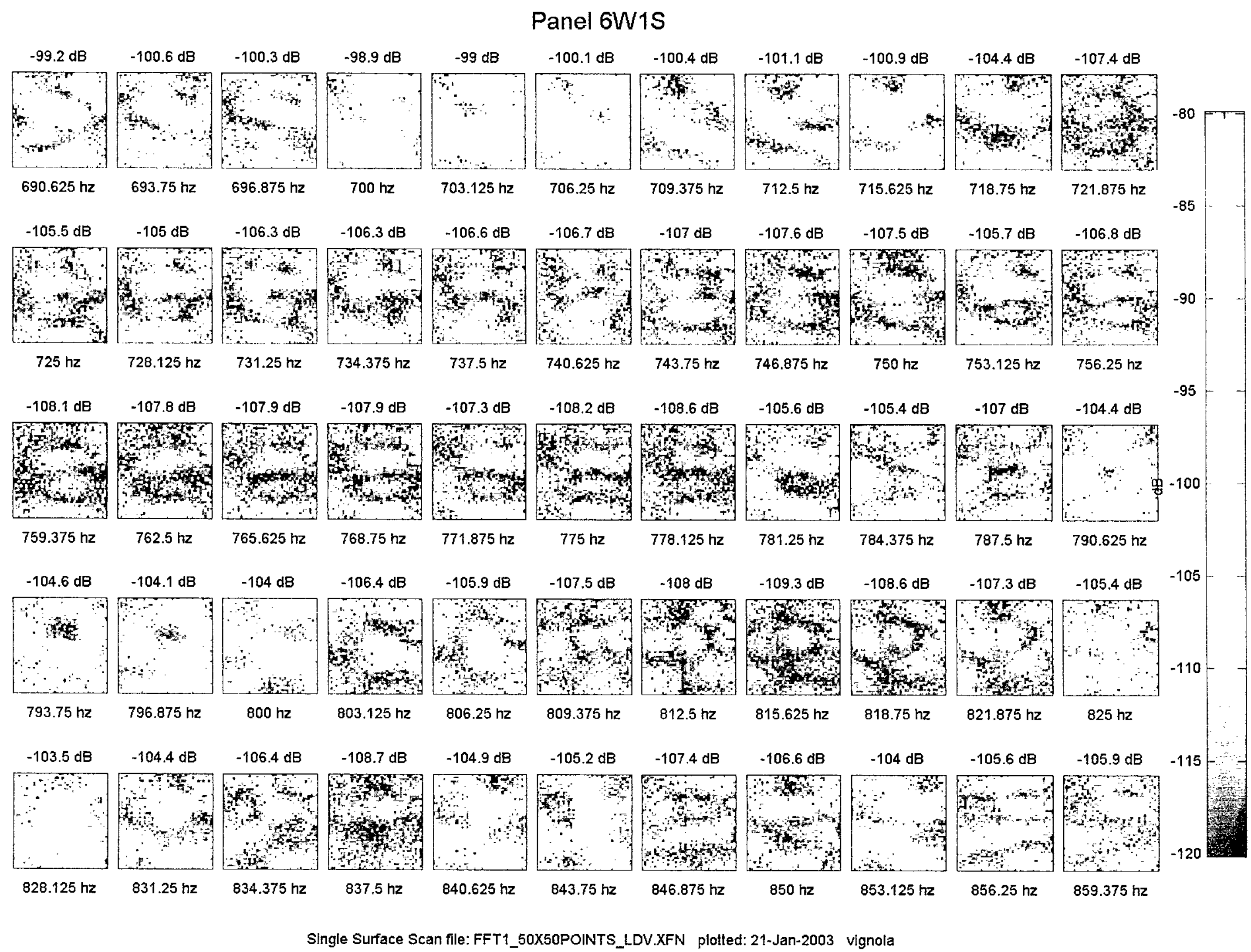

Panel 6W1S
-99.2 dB
690.625 hz
-100.6 dB
693.75 hz
-100.3 dB
696.875 hz
-98.9 dB
700 hz
-99 dB
703.125 hz
-100.1 dB
706.25 hz
-100.4 dB
709.375 hz
-101.1 dB
712.5 hz
-100.9 dB
715.625 hz
-104.4 dB
718.75 hz
-107.4 dB
721.875 hz
-105.5 dB
725 hz
-105 dB
728.125 hz
-106.3 dB
731.25 hz
-106.3 dB
734.375 hz
-106.6 dB
737.5 hz
-106.7 dB
740.625 hz
-107 dB
743.75 hz
-107.6 dB
746.875 hz
-107.5 dB
750 hz
-105.7 dB
753.125 hz
-106.8 dB
756.25 hz
-108.1 dB
759.375 hz
-107.8 dB
762.5 hz
-107.9 dB
765.625 hz
-107.9 dB
768.75 hz
-107.3 dB
771.875 hz
-108.2 dB
775 hz
-108.6 dB
778.125 hz
-105.6 dB
781.25 hz
-105.4 dB
784.375 hz
-107 dB
787.5 hz
-104.4 dB
790.625 hz
-104.6 dB
793.75 hz
-104.1 dB
796.875 hz
-104 dB
800 hz
-106.4 dB
803.125 hz
-105.9 dB
806.25 hz
-107.5 dB
809.375 hz
-108 dB
812.5 hz
-109.3 dB
815.625 hz
-108.6 dB
818.75 hz
-107.3 dB
821.875 hz
-105.4 dB
825 hz
-103.5 dB
828.125 hz
-104.4 dB
831.25 hz
-106.4 dB
834.375 hz
-108.7 dB
837.5 hz
-104.9 dB
840.625 hz
-105.2 dB
843.75 hz
-107.4 dB
846.875 hz
-106.6 dB
850 hz
-104 dB
853.125 hz
-105.6 dB
856.25 hz
-105.9 dB
859.375 hz
dB
-80
-85
-90
-95
-100
-105
-110
-115
-120
Single Surface Scan file: FFT1_50X50POINTS_LDV.XFN plotted: 21-Jan-2003 vignola

Figure 3e

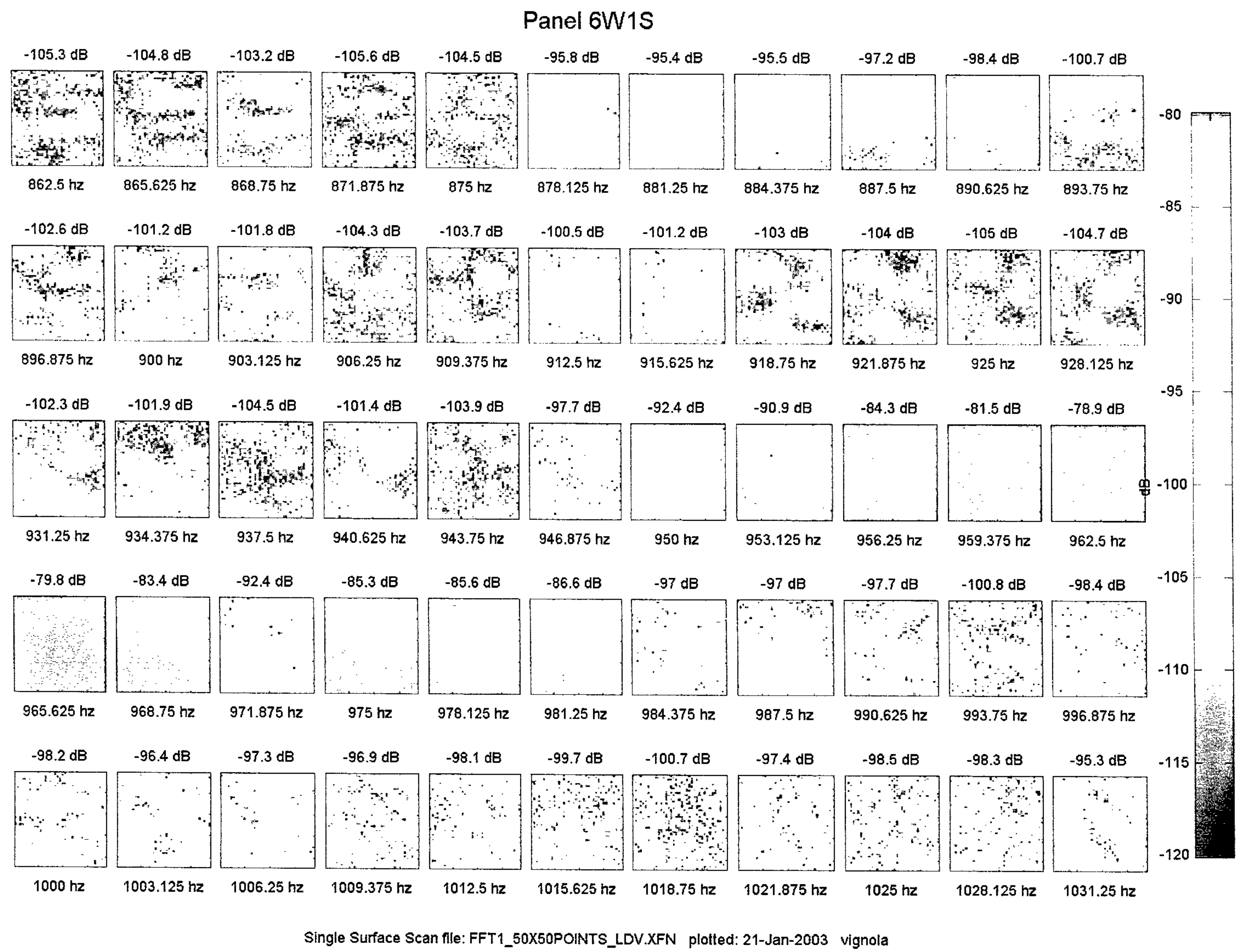
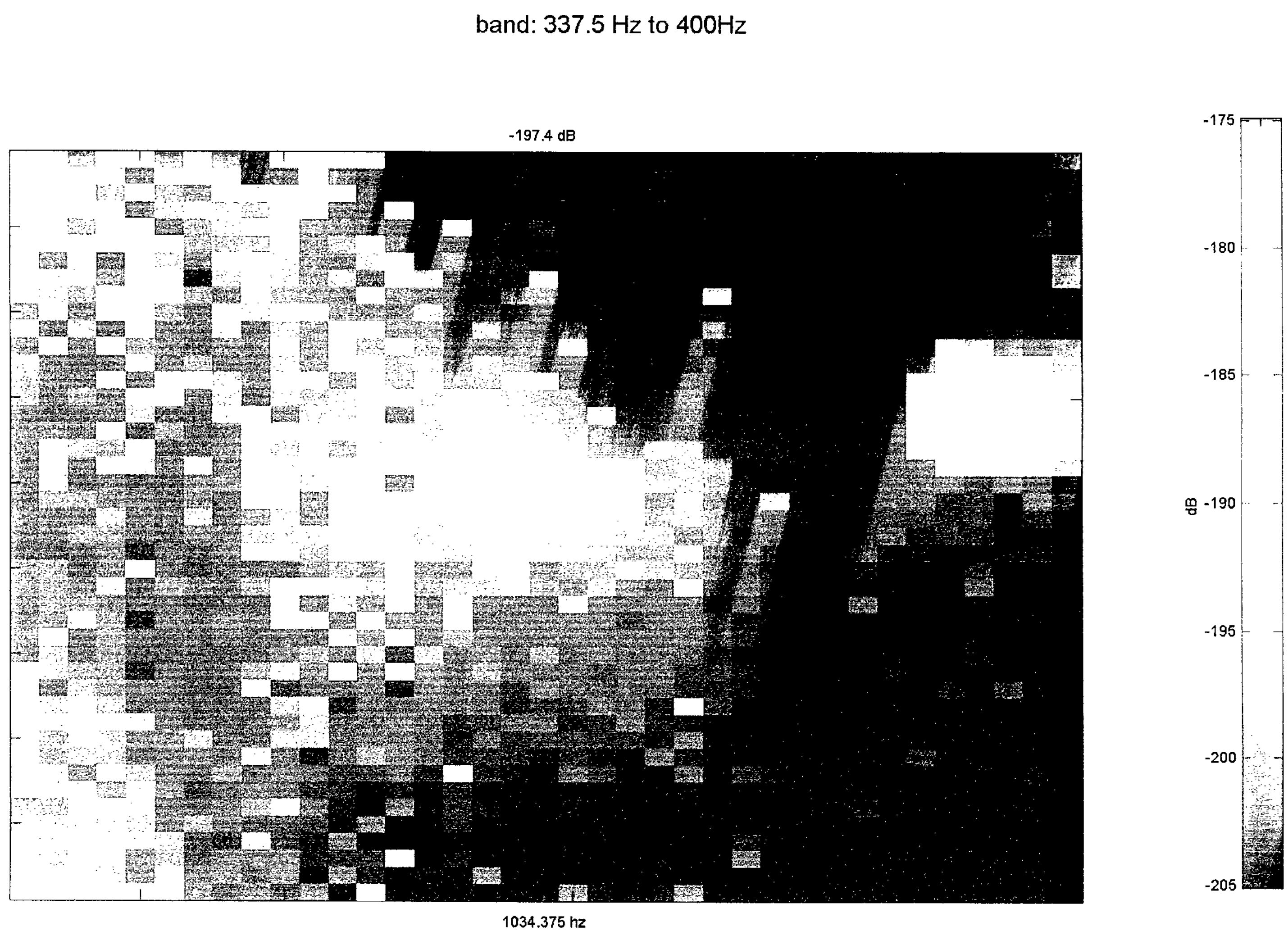

Panel 6W1S
-105.3 dB
862.5 hz
-104.8 dB
865.625 hz
-103.2 dB
868.75 hz
-105.6 dB
871.875 hz
-104.5 dB
875 hz
-95.8 dB
878.125 hz
-95.4 dB
881.25 hz
-95.5 dB
884.375 hz
-97.2 dB
887.5 hz
-98.4 dB
890.625 hz
-100.7 dB
893.75 hz
-102.6 dB
896.875 hz
-101.2 dB
900 hz
-101.8 dB
903.125 hz
-104.3 dB
906.25 hz
-103.7 dB
909.375 hz
-100.5 dB
912.5 hz
-101.2 dB
915.625 hz
-103 dB
918.75 hz
-104 dB
921.875 hz
-105 dB
925 hz
-104.7 dB
928.125 hz
-102.3 dB
931.25 hz
-101.9 dB
934.375 hz
-104.5 dB
937.5 hz
-101.4 dB
940.625 hz
-103.9 dB
943.75 hz
-97.7 dB
946.875 hz
-92.4 dB
950 hz
-90.9 dB
953.125 hz
-84.3 dB
956.25 hz
-81.5 dB
959.375 hz
-78.9 dB
962.5 hz
-79.8 dB
965.625 hz
-83.4 dB
968.75 hz
-92.4 dB
971.875 hz
-85.3 dB
975 hz
-85.6 dB
978.125 hz
-86.6 dB
981.25 hz
-97 dB
984.375 hz
-97 dB
987.5 hz
-97.7 dB
990.625 hz
-100.8 dB
993.75 hz
-98.4 dB
996.875 hz
-98.2 dB
1000 hz
-96.4 dB
1003.125 hz
-97.3 dB
1006.25 hz
-96.9 dB
1009.375 hz
-98.1 dB
1012.5 hz
-99.7 dB
1015.625 hz
-100.7 dB
1018.75 hz
-97.4 dB
1021.875 hz
-98.5 dB
1025 hz
-98.3 dB
1028.125 hz
-95.3 dB
1031.25 hz
dB
-80
-85
-90
-95
-100
-105
-110
-115
-120
Single Surface Scan file: FFT1_50X50POINTS_LDV.XFN plotted: 21-Jan-2003 vignola

Figure 3f



Single Surface Scan file: FFT1_50X50POINTS_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 4a

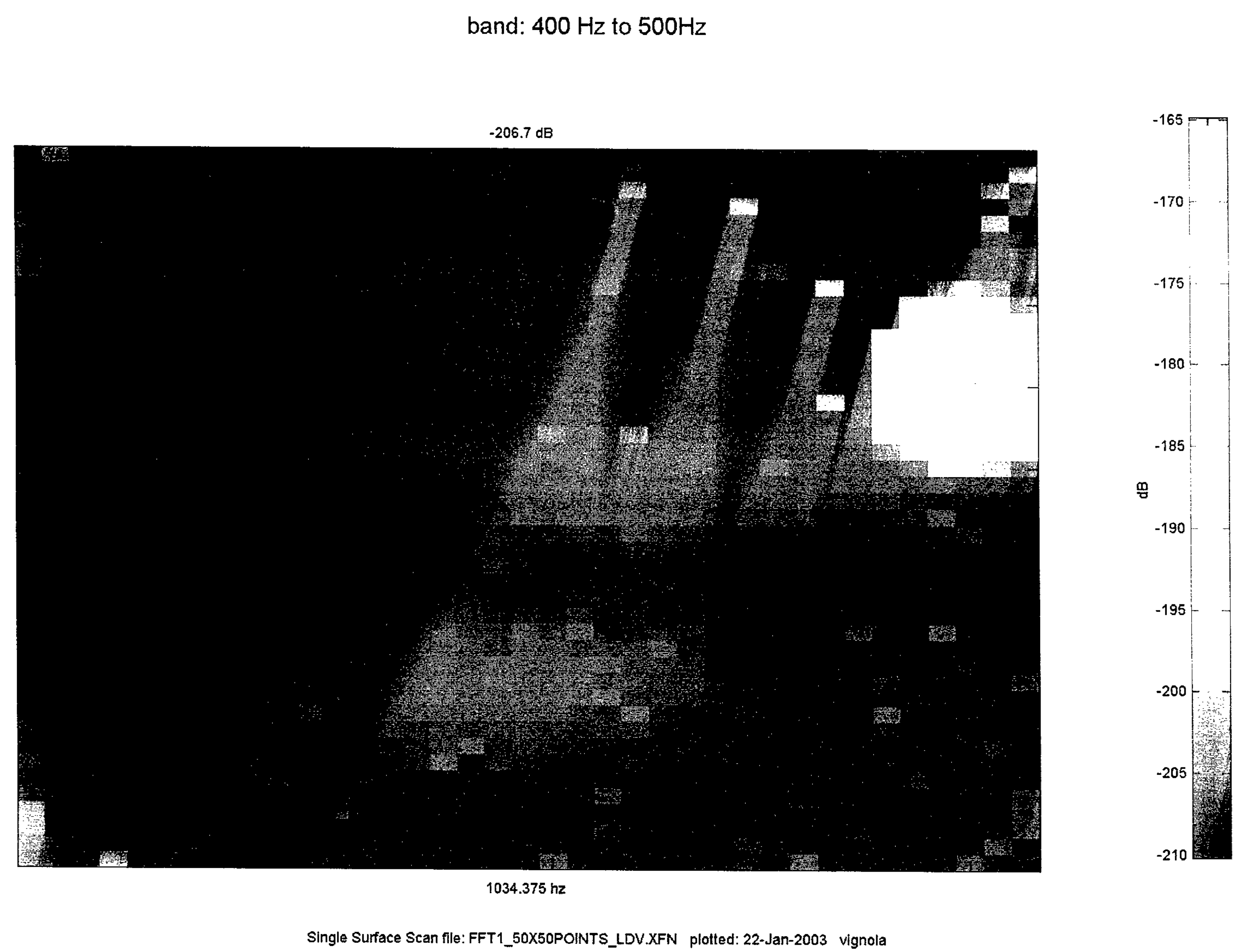

band: 400 Hz to 500Hz
-206.7 dB
1034.375 hz
-165
-170
-175
-180
-185
-190
-195
-200
-205
-210
dB
Single Surface Scan file: FFT1_50X50POINTS_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 4b

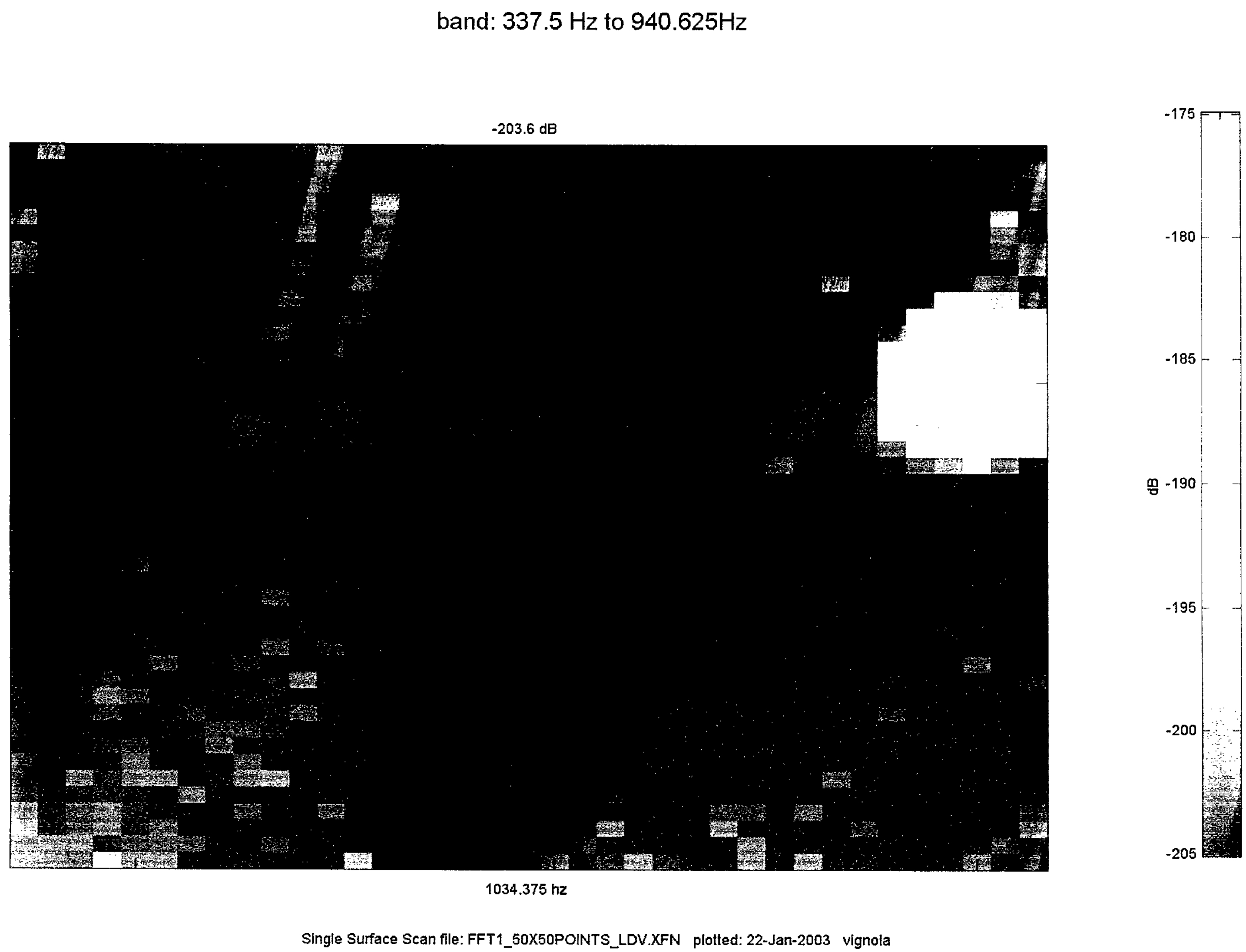
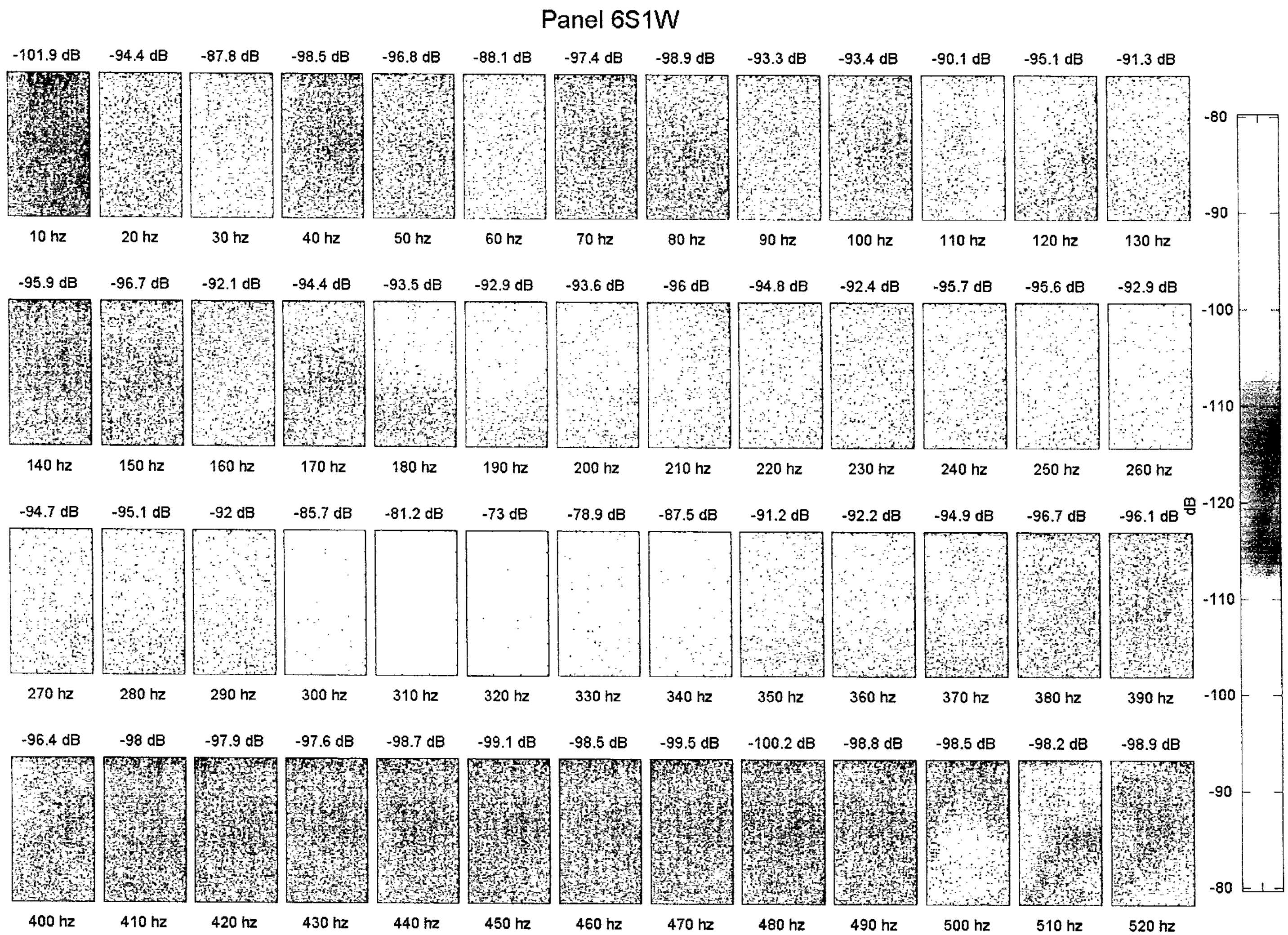
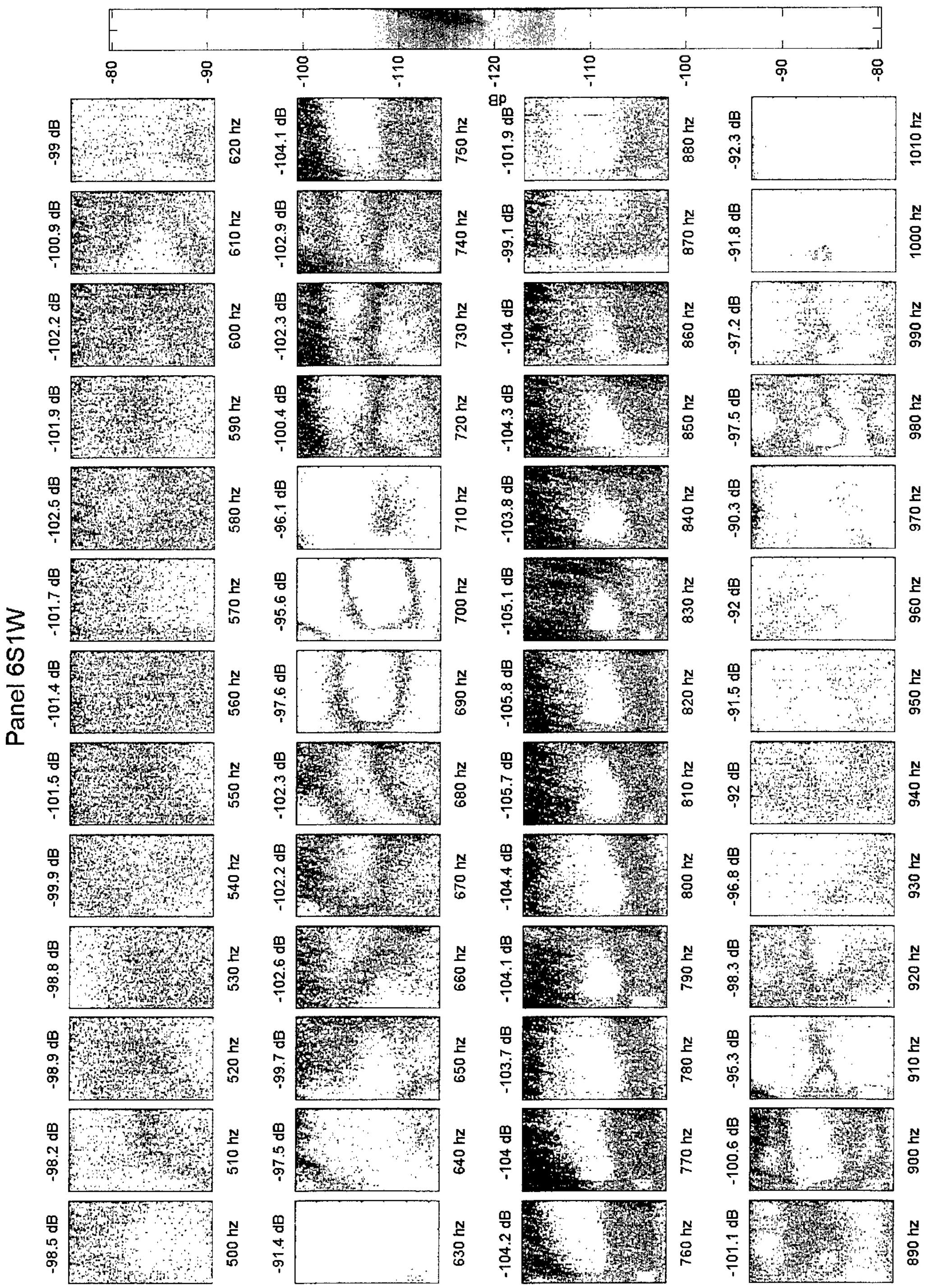

band: 337.5 Hz to 940.625Hz
-203.6 dB
1034.375 hz
-175
-180
-185
-190
-195
-200
-205
dB
Single Surface Scan file: FFT1_50X50POINTS_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 4c



Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6a

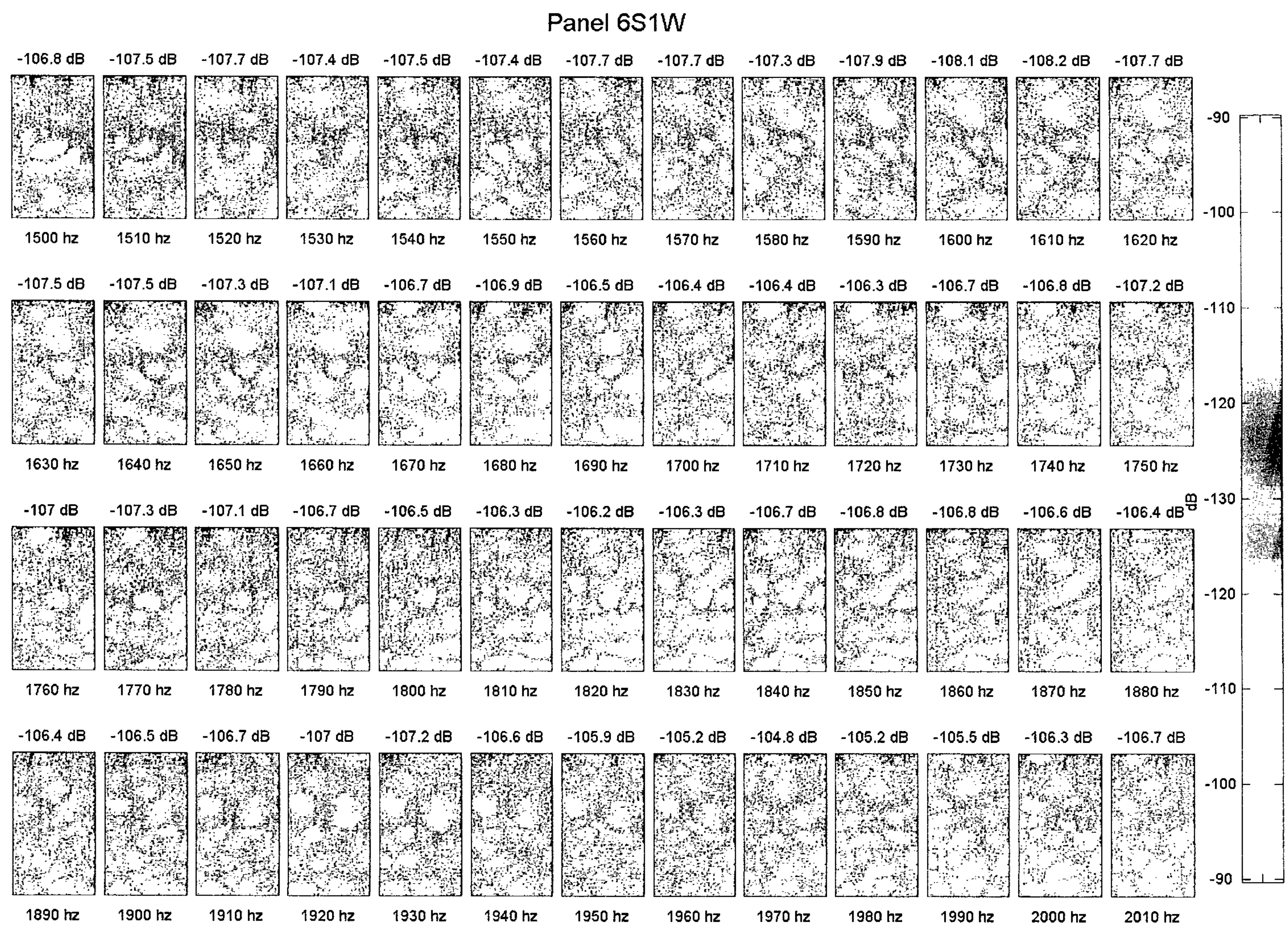


Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6b

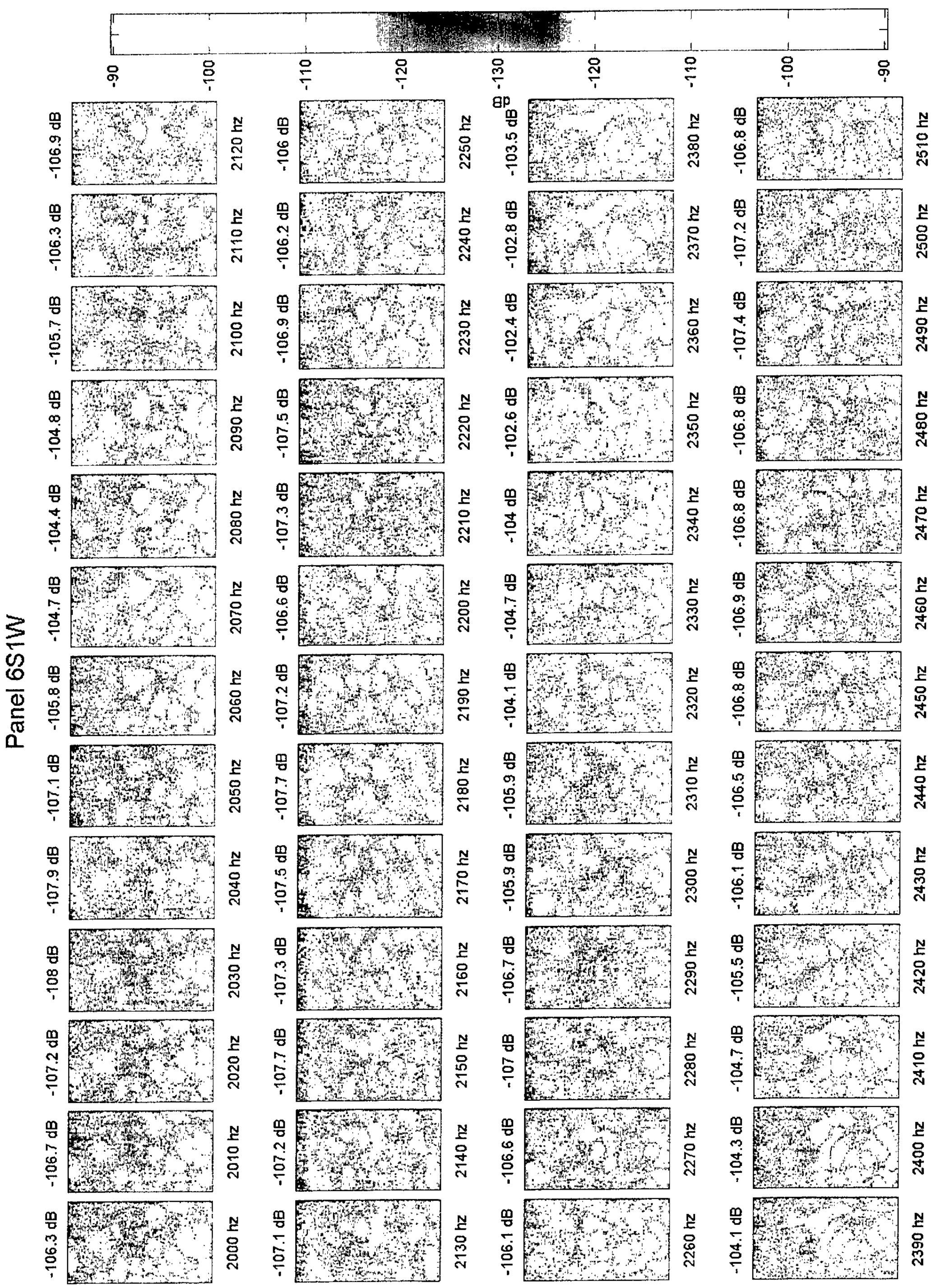
Panel 6S1W
-91.8 dB
1000 hz
-92.3 dB
1010 hz
-101.2 dB
1020 hz
-95.4 dB
1030 hz
-99.8 dB
1040 hz
-101.7 dB
1050 hz
-97.5 dB
1060 hz
-97.2 dB
1070 hz
-96.8 dB
1080 hz
-95.1 dB
1090 hz
-95.4 dB
1100 hz
-100.3 dB
1110 hz
-99.6 dB
1120 hz
-100.2 dB
1130 hz
-100.4 dB
1140 hz
-100.7 dB
1150 hz
-100.3 dB
1160 hz
-98.4 dB
1170 hz
-98.3 dB
1180 hz
-98.5 dB
1190 hz
-100.2 dB
1200 hz
-100 dB
1210 hz
-99.6 dB
1220 hz
-100.3 dB
1230 hz
-101.1 dB
1240 hz
-101.2 dB
1250 hz
-100.5 dB
1260 hz
-99.7 dB
1270 hz
-100.9 dB
1280 hz
-101.9 dB
1290 hz
-103.2 dB
1300 hz
-104.5 dB
1310 hz
-105.8 dB
1320 hz
-106.1 dB
1330 hz
-105.5 dB
1340 hz
-105.5 dB
1350 hz
-105.4 dB
1360 hz
-105.1 dB
1370 hz
-104.9 dB
1380 hz
-104.6 dB
1390 hz
-104.3 dB
1400 hz
-103.5 dB
1410 hz
-103.1 dB
1420 hz
-102.7 dB
1430 hz
-102.9 dB
1440 hz
-103.9 dB
1450 hz
-104.5 dB
1460 hz
-104.6 dB
1470 hz
-104.7 dB
1480 hz
-105.6 dB
1490 hz
-106.8 dB
1500 hz
-107.5 dB
1510 hz
-80
-90
-100
-110
-120
-110
-100
-90
-80
dB
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6c



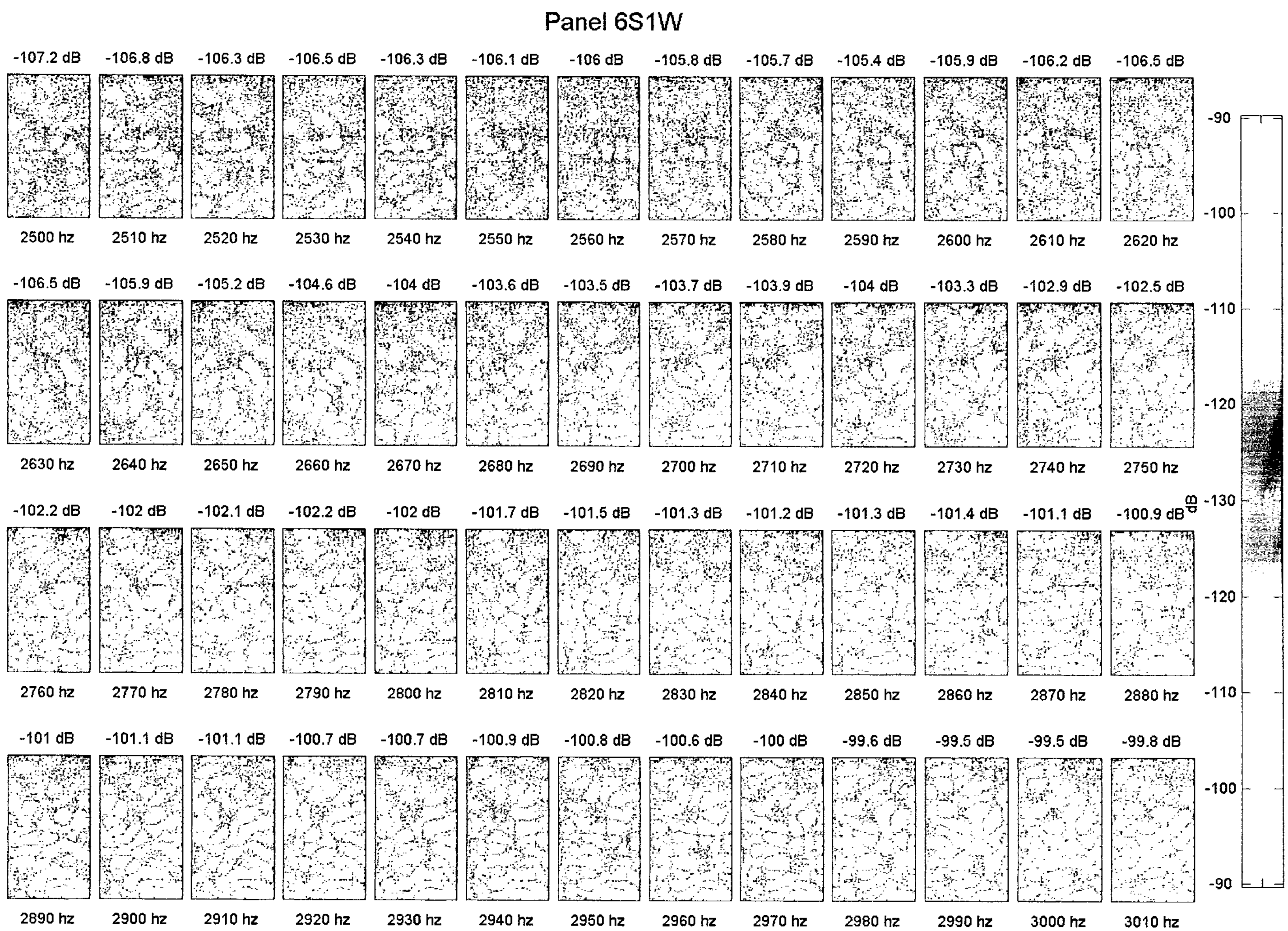
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6d



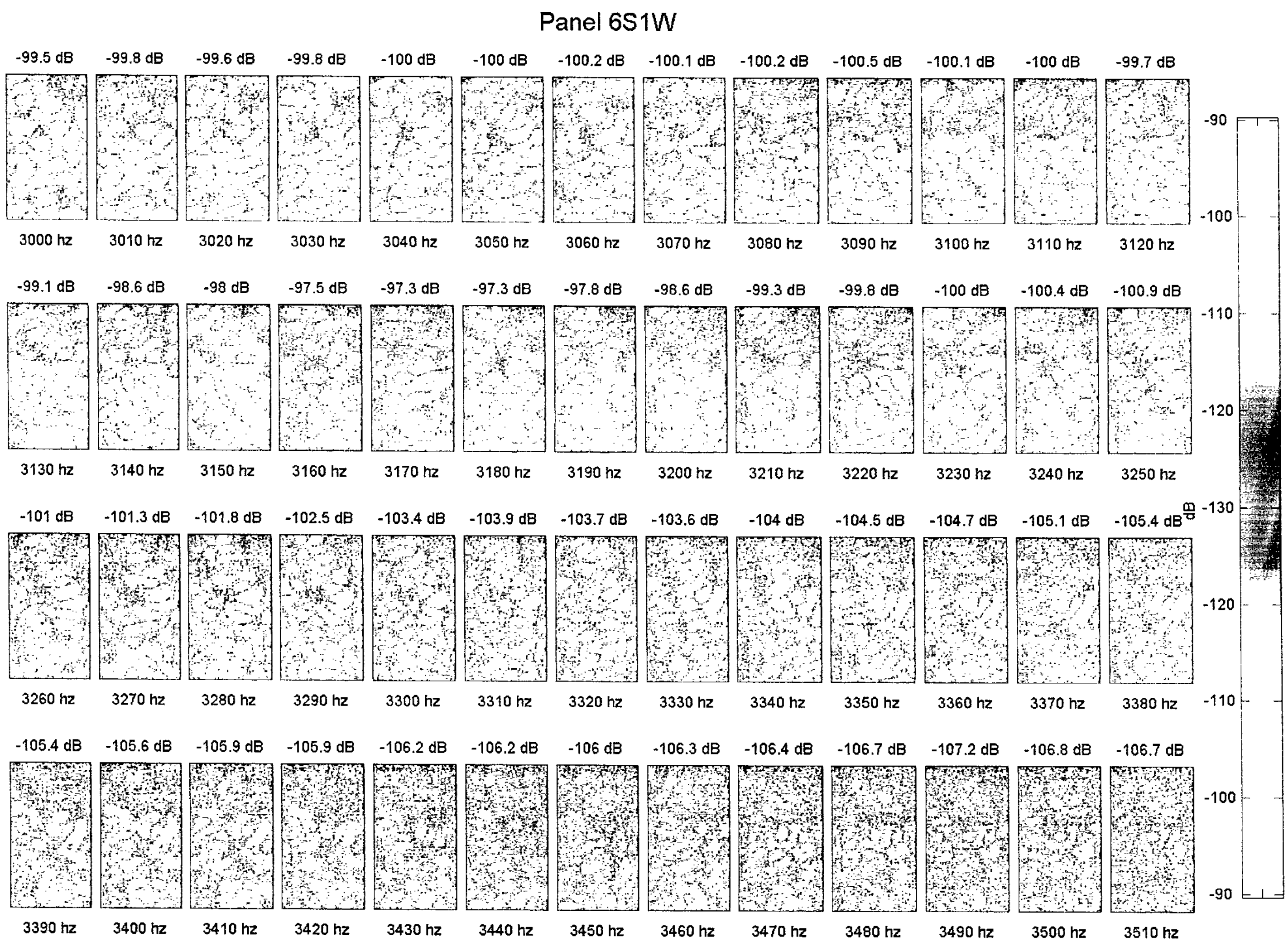
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6e



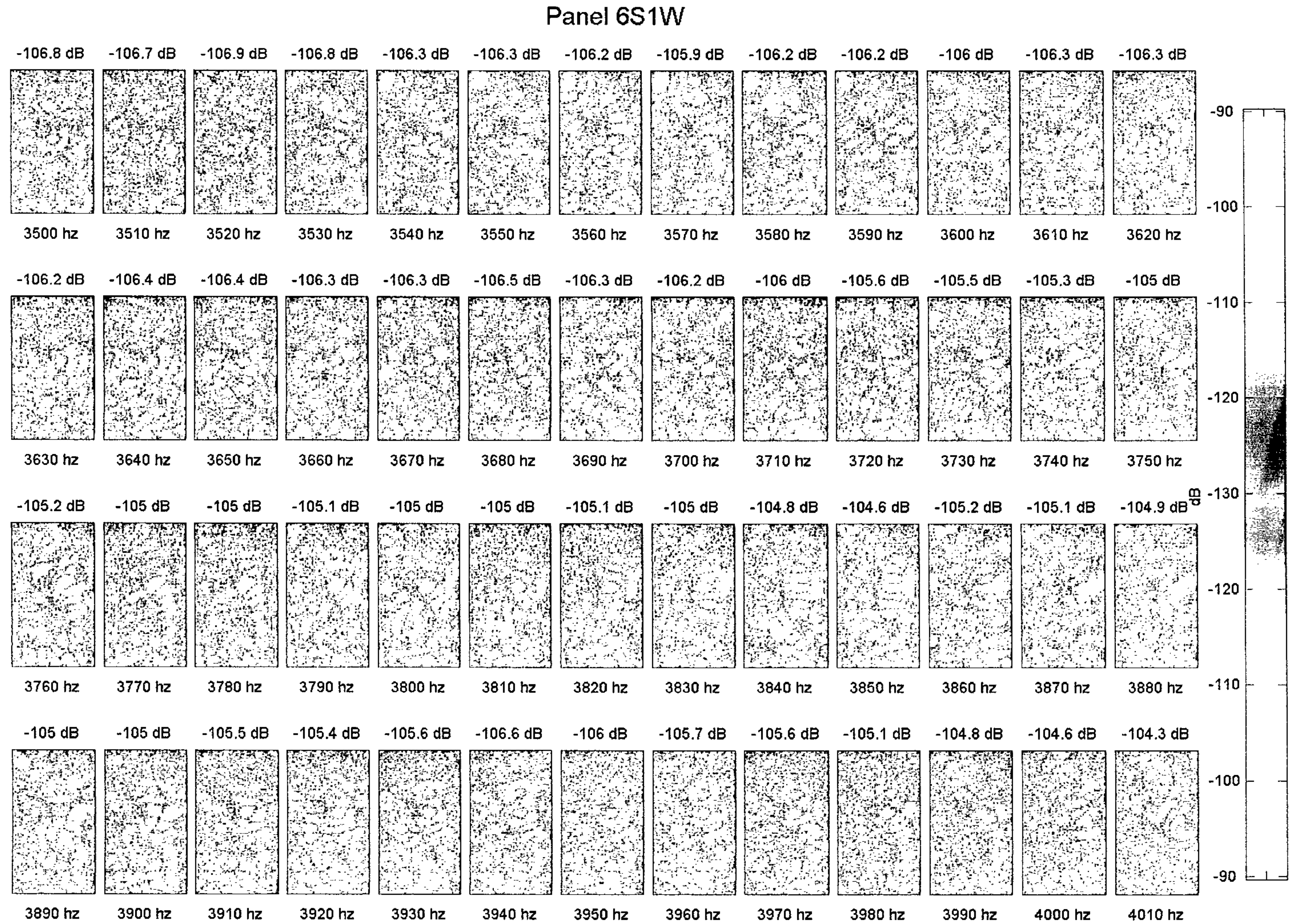
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6f



Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6g



Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6h

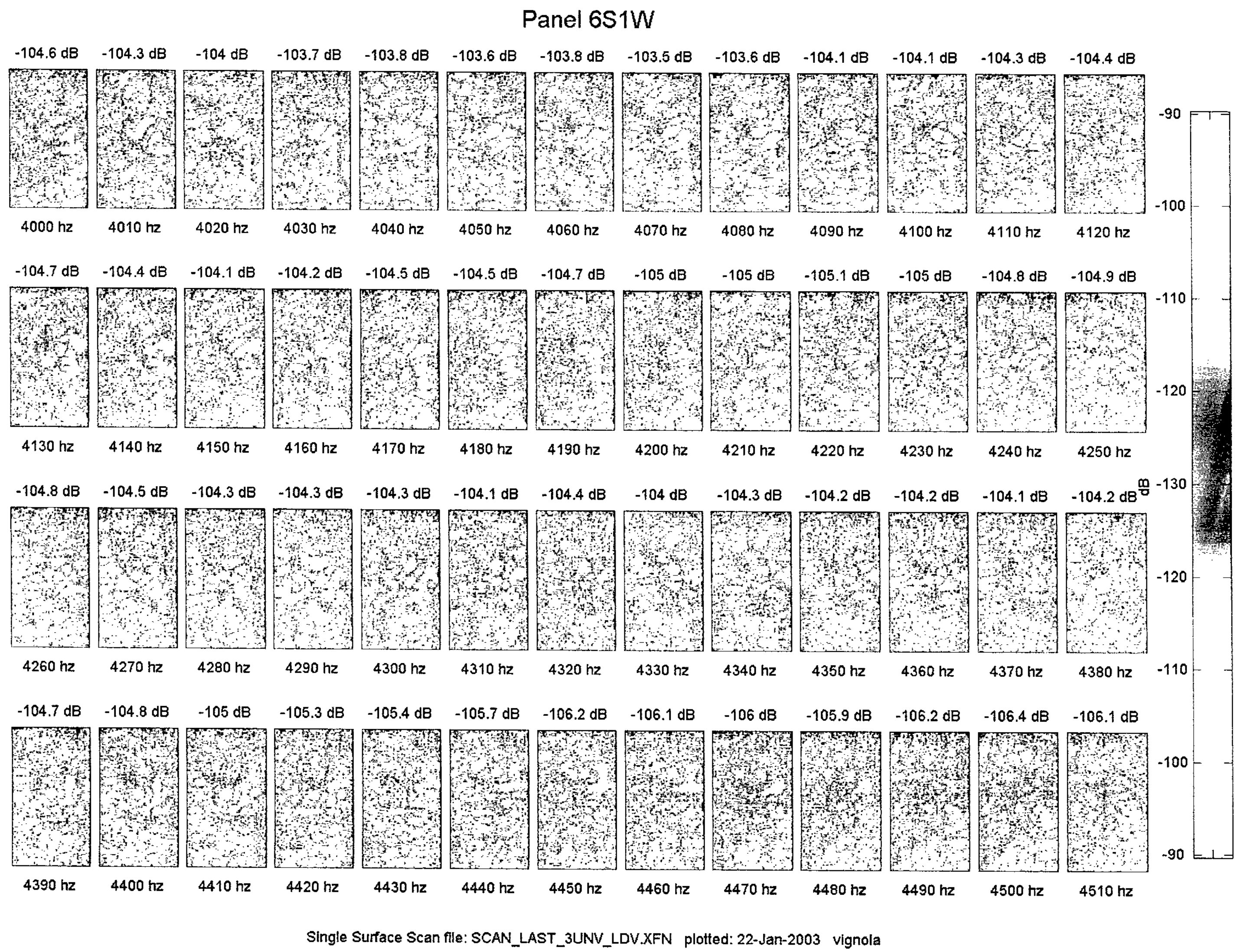

Panel 6S1W
-104.6 dB
4000 hz
-104.3 dB
4010 hz
-104 dB
4020 hz
-103.7 dB
4030 hz
-103.8 dB
4040 hz
-103.6 dB
4050 hz
-103.8 dB
4060 hz
-103.5 dB
4070 hz
-103.6 dB
4080 hz
-104.1 dB
4090 hz
-104.1 dB
4100 hz
-104.3 dB
4110 hz
-104.4 dB
4120 hz
-104.7 dB
4130 hz
-104.4 dB
4140 hz
-104.1 dB
4150 hz
-104.2 dB
4160 hz
-104.5 dB
4170 hz
-104.5 dB
4180 hz
-104.7 dB
4190 hz
-105 dB
4200 hz
-105 dB
4210 hz
-105.1 dB
4220 hz
-105 dB
4230 hz
-104.8 dB
4240 hz
-104.9 dB
4250 hz
-104.8 dB
4260 hz
-104.5 dB
4270 hz
-104.3 dB
4280 hz
-104.3 dB
4290 hz
-104.3 dB
4300 hz
-104.1 dB
4310 hz
-104.4 dB
4320 hz
-104 dB
4330 hz
-104.3 dB
4340 hz
-104.2 dB
4350 hz
-104.2 dB
4360 hz
-104.1 dB
4370 hz
-104.2 dB
4380 hz
-104.7 dB
4390 hz
-104.8 dB
4400 hz
-105 dB
4410 hz
-105.3 dB
4420 hz
-105.4 dB
4430 hz
-105.7 dB
4440 hz
-106.2 dB
4450 hz
-106.1 dB
4460 hz
-106 dB
4470 hz
-105.9 dB
4480 hz
-106.2 dB
4490 hz
-106.4 dB
4500 hz
-106.1 dB
4510 hz
dB
-90
-100
-110
-120
-130
-120
-110
-100
-90
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6i

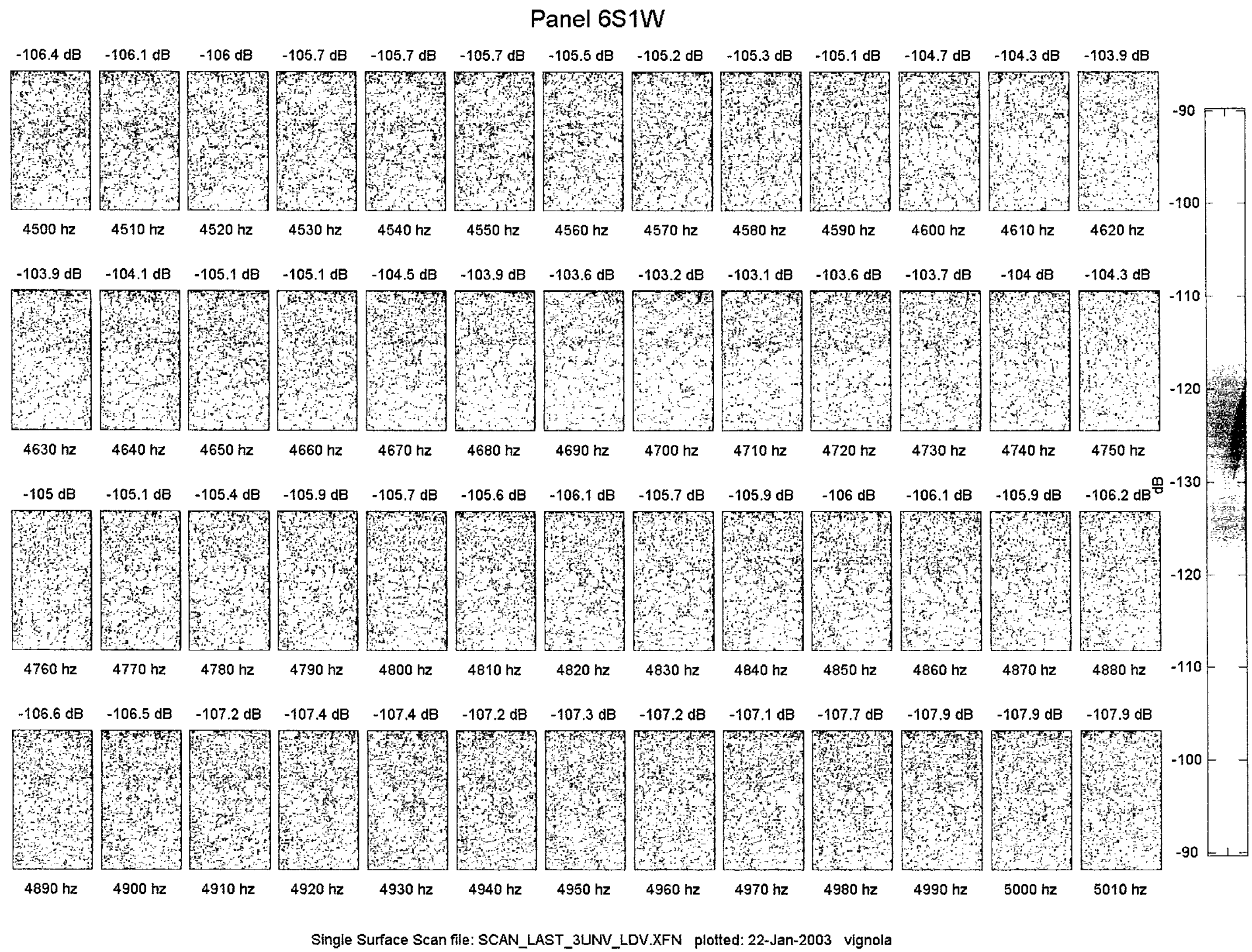

Panel 6S1W
-106.4 dB
-106.1 dB
-106 dB
-105.7 dB
-105.7 dB
-105.7 dB
-105.5 dB
-105.2 dB
-105.3 dB
-105.1 dB
-104.7 dB
-104.3 dB
-103.9 dB
4500 hz
4510 hz
4520 hz
4530 hz
4540 hz
4550 hz
4560 hz
4570 hz
4580 hz
4590 hz
4600 hz
4610 hz
4620 hz
-103.9 dB
-104.1 dB
-105.1 dB
-105.1 dB
-104.5 dB
-103.9 dB
-103.6 dB
-103.2 dB
-103.1 dB
-103.6 dB
-103.7 dB
-104 dB
-104.3 dB
4630 hz
4640 hz
4650 hz
4660 hz
4670 hz
4680 hz
4690 hz
4700 hz
4710 hz
4720 hz
4730 hz
4740 hz
4750 hz
-105 dB
-105.1 dB
-105.4 dB
-105.9 dB
-105.7 dB
-105.6 dB
-106.1 dB
-105.7 dB
-105.9 dB
-106 dB
-106.1 dB
-105.9 dB
-106.2 dB
4760 hz
4770 hz
4780 hz
4790 hz
4800 hz
4810 hz
4820 hz
4830 hz
4840 hz
4850 hz
4860 hz
4870 hz
4880 hz
-106.6 dB
-106.5 dB
-107.2 dB
-107.4 dB
-107.4 dB
-107.2 dB
-107.3 dB
-107.2 dB
-107.1 dB
-107.7 dB
-107.9 dB
-107.9 dB
-107.9 dB
4890 hz
4900 hz
4910 hz
4920 hz
4930 hz
4940 hz
4950 hz
4960 hz
4970 hz
4980 hz
4990 hz
5000 hz
5010 hz
dB
-90
-100
-110
-120
-130
-120
-110
-100
-90
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6j

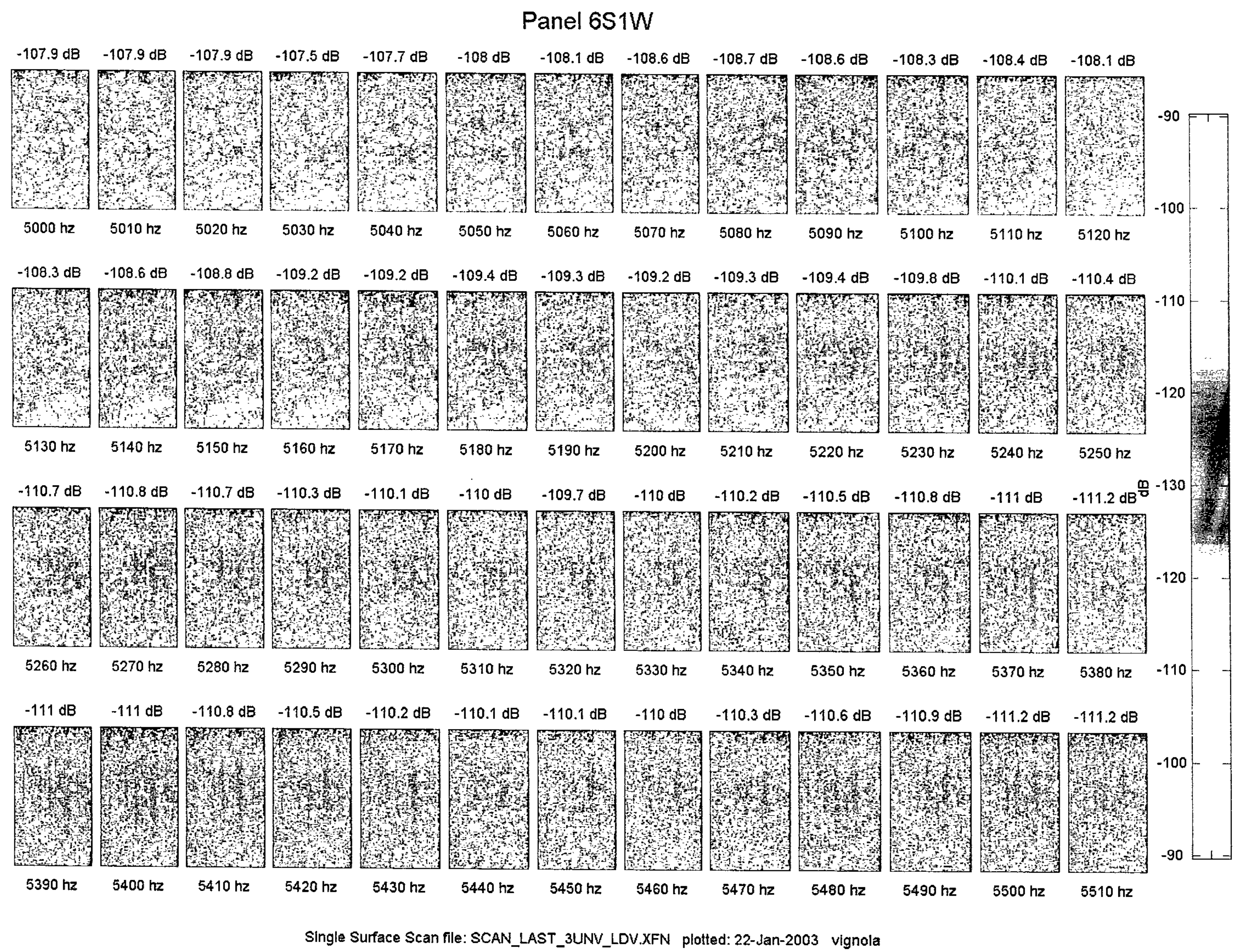
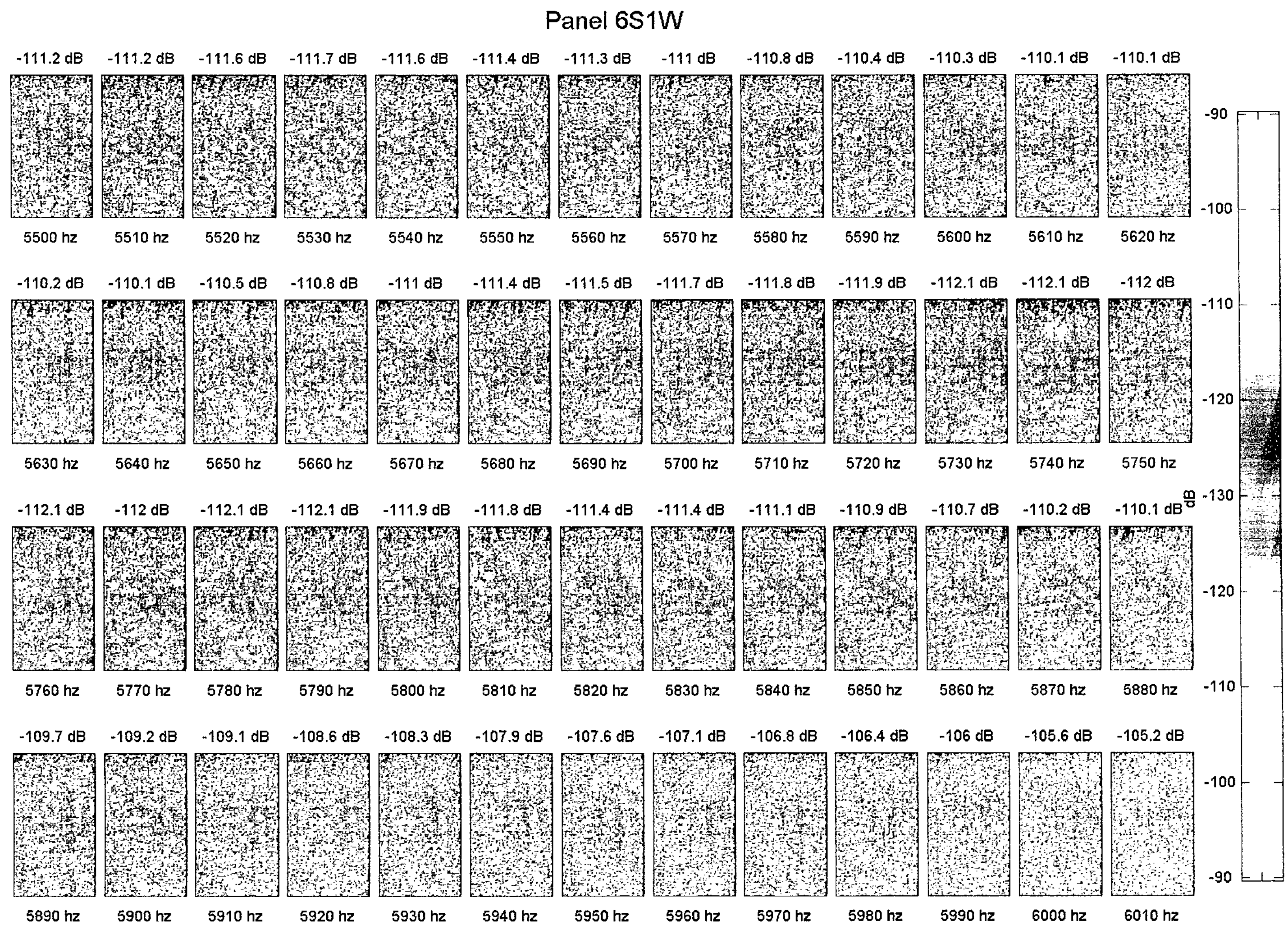
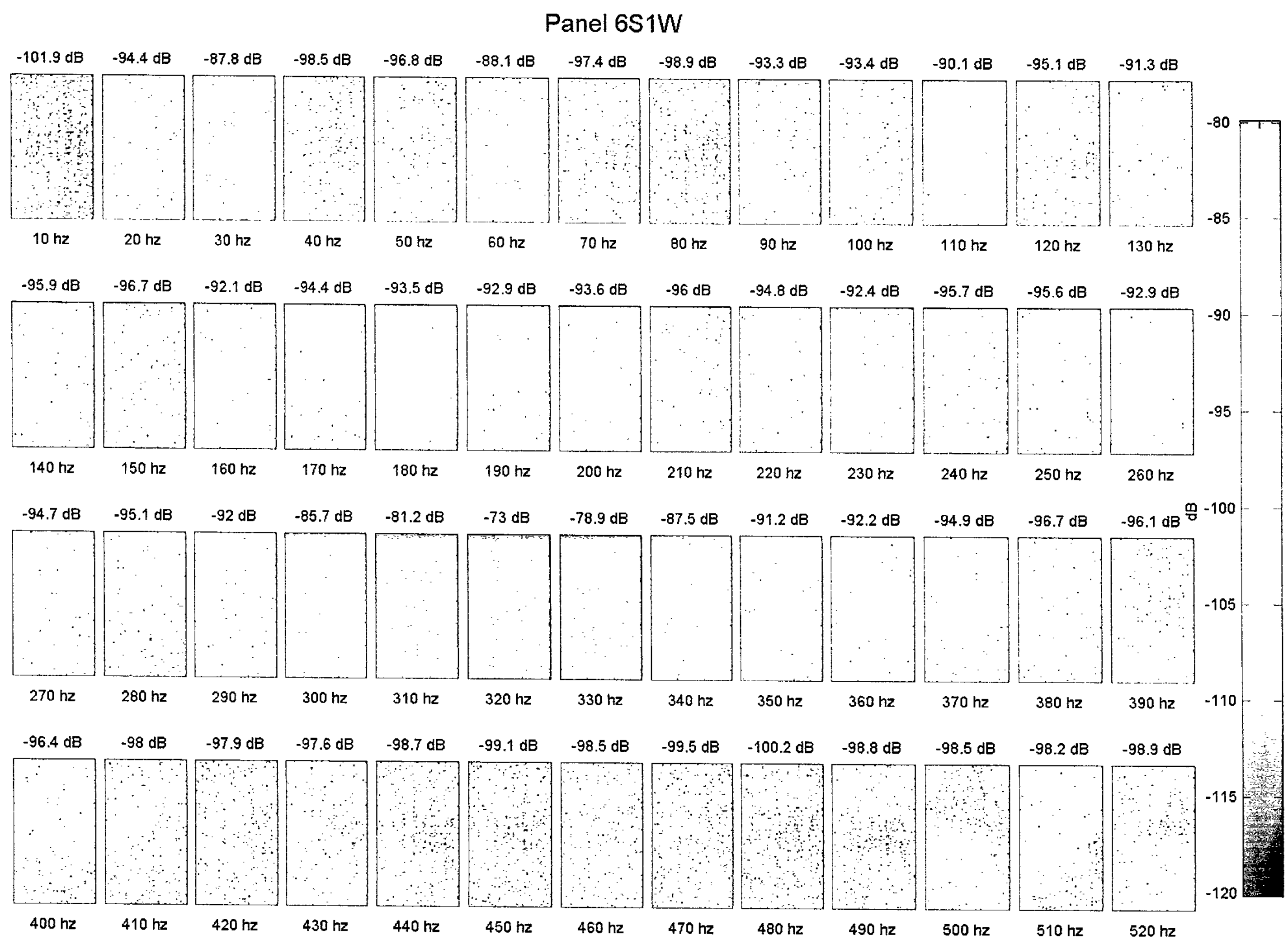

Panel 6S1W
-107.9 dB
-107.9 dB
-107.9 dB
-107.5 dB
-107.7 dB
-108 dB
-108.1 dB
-108.6 dB
-108.7 dB
-108.6 dB
-108.3 dB
-108.4 dB
-108.1 dB
5000 hz
5010 hz
5020 hz
5030 hz
5040 hz
5050 hz
5060 hz
5070 hz
5080 hz
5090 hz
5100 hz
5110 hz
5120 hz
-108.3 dB
-108.6 dB
-108.8 dB
-109.2 dB
-109.2 dB
-109.4 dB
-109.3 dB
-109.2 dB
-109.3 dB
-109.4 dB
-109.8 dB
-110.1 dB
-110.4 dB
5130 hz
5140 hz
5150 hz
5160 hz
5170 hz
5180 hz
5190 hz
5200 hz
5210 hz
5220 hz
5230 hz
5240 hz
5250 hz
-110.7 dB
-110.8 dB
-110.7 dB
-110.3 dB
-110.1 dB
-110 dB
-109.7 dB
-110 dB
-110.2 dB
-110.5 dB
-110.8 dB
-111 dB
-111.2 dB
5260 hz
5270 hz
5280 hz
5290 hz
5300 hz
5310 hz
5320 hz
5330 hz
5340 hz
5350 hz
5360 hz
5370 hz
5380 hz
-111 dB
-111 dB
-110.8 dB
-110.5 dB
-110.2 dB
-110.1 dB
-110.1 dB
-110 dB
-110.3 dB
-110.6 dB
-110.9 dB
-111.2 dB
-111.2 dB
5390 hz
5400 hz
5410 hz
5420 hz
5430 hz
5440 hz
5450 hz
5460 hz
5470 hz
5480 hz
5490 hz
5500 hz
5510 hz
dB
-90
-100
-110
-120
-130
-120
-110
-100
-90
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6k



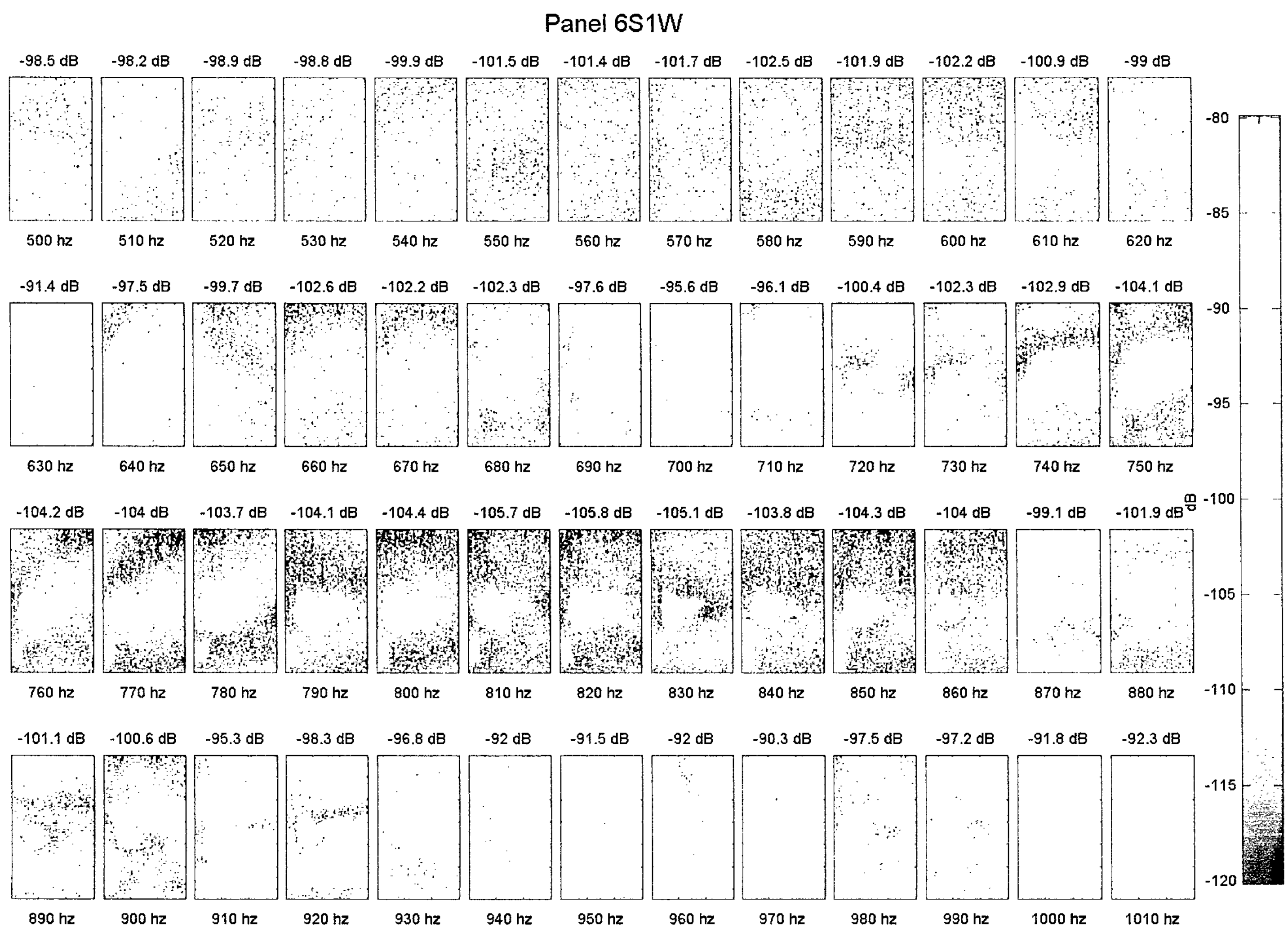
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6l



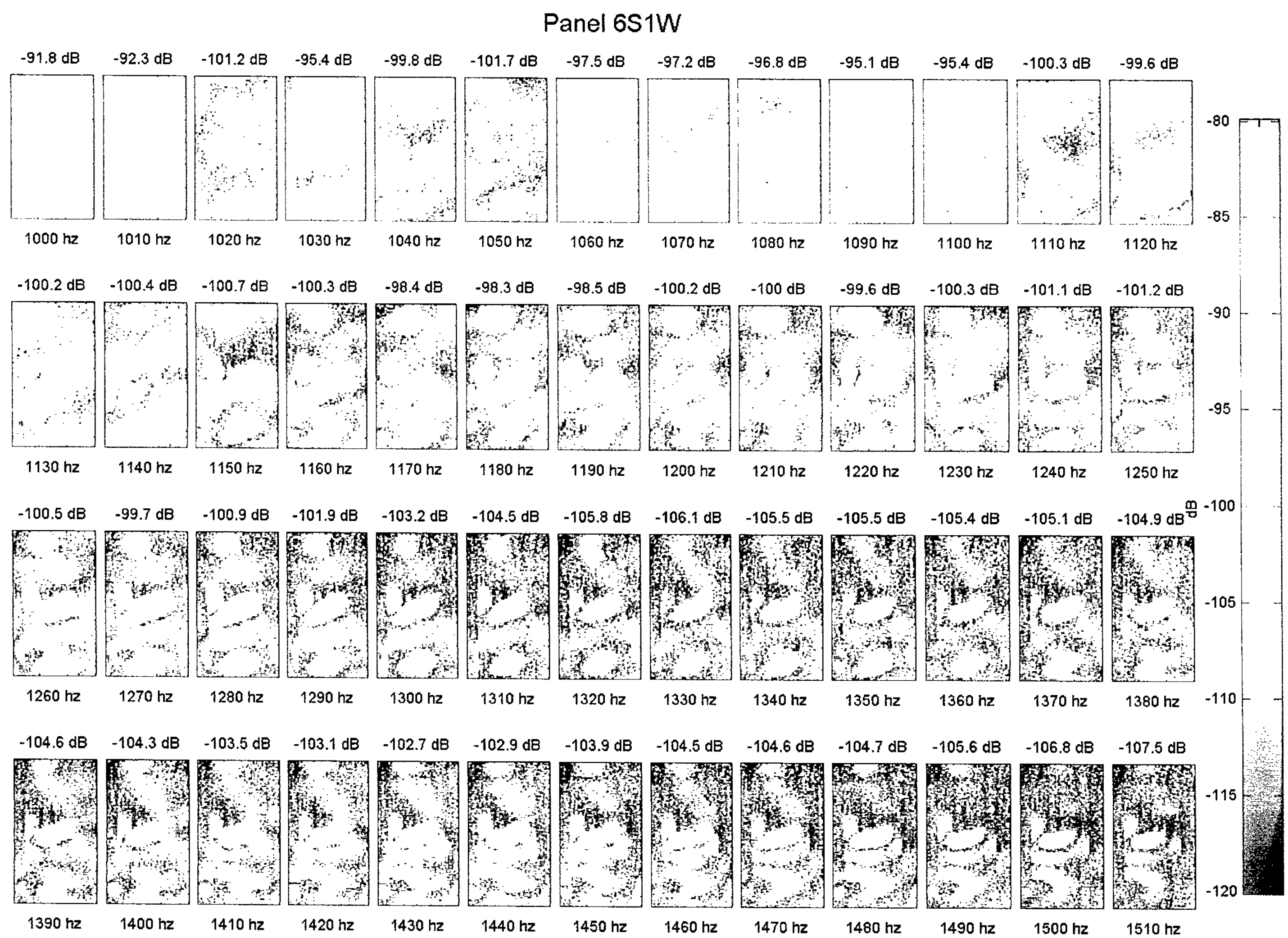
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6m



Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6n



Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6o

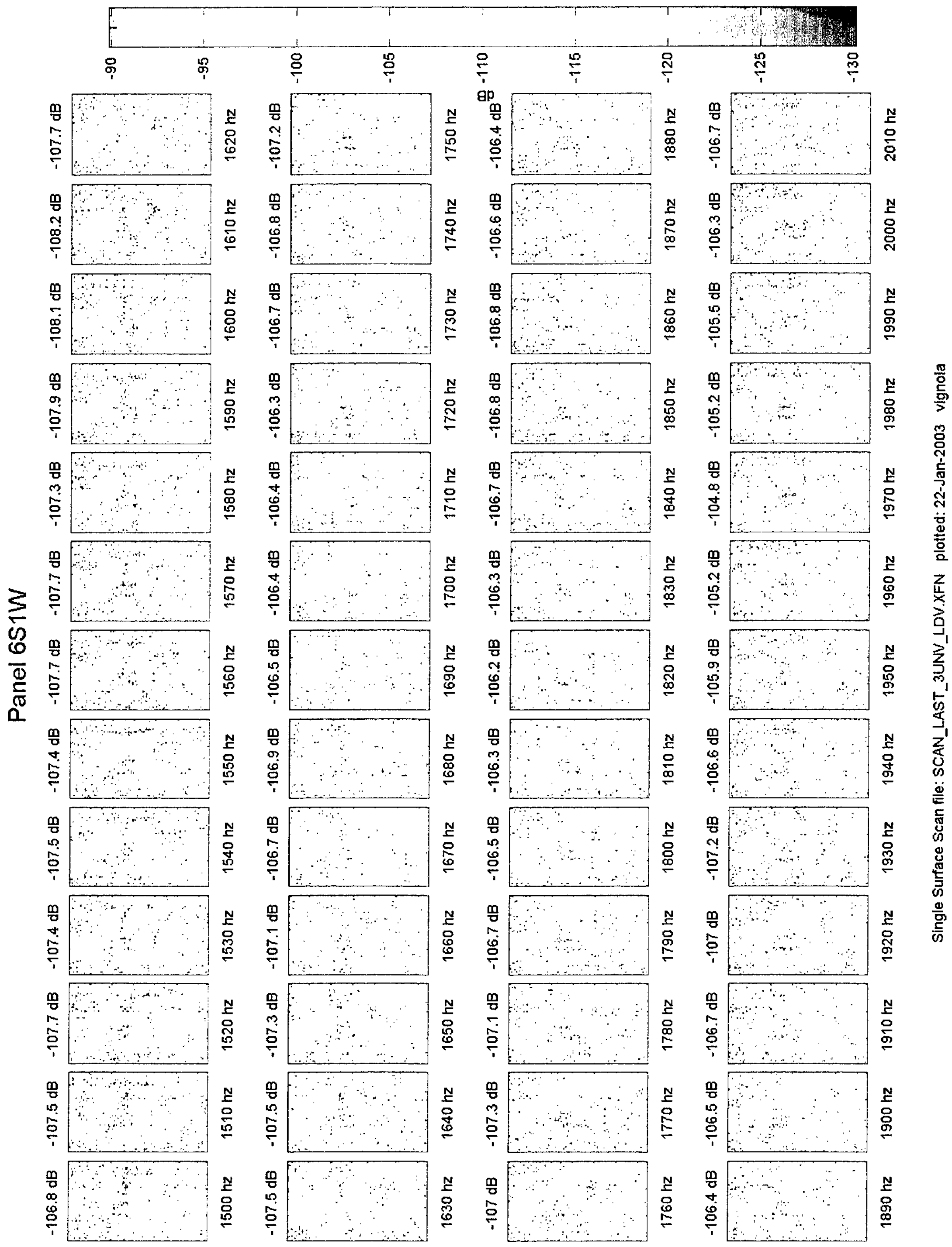
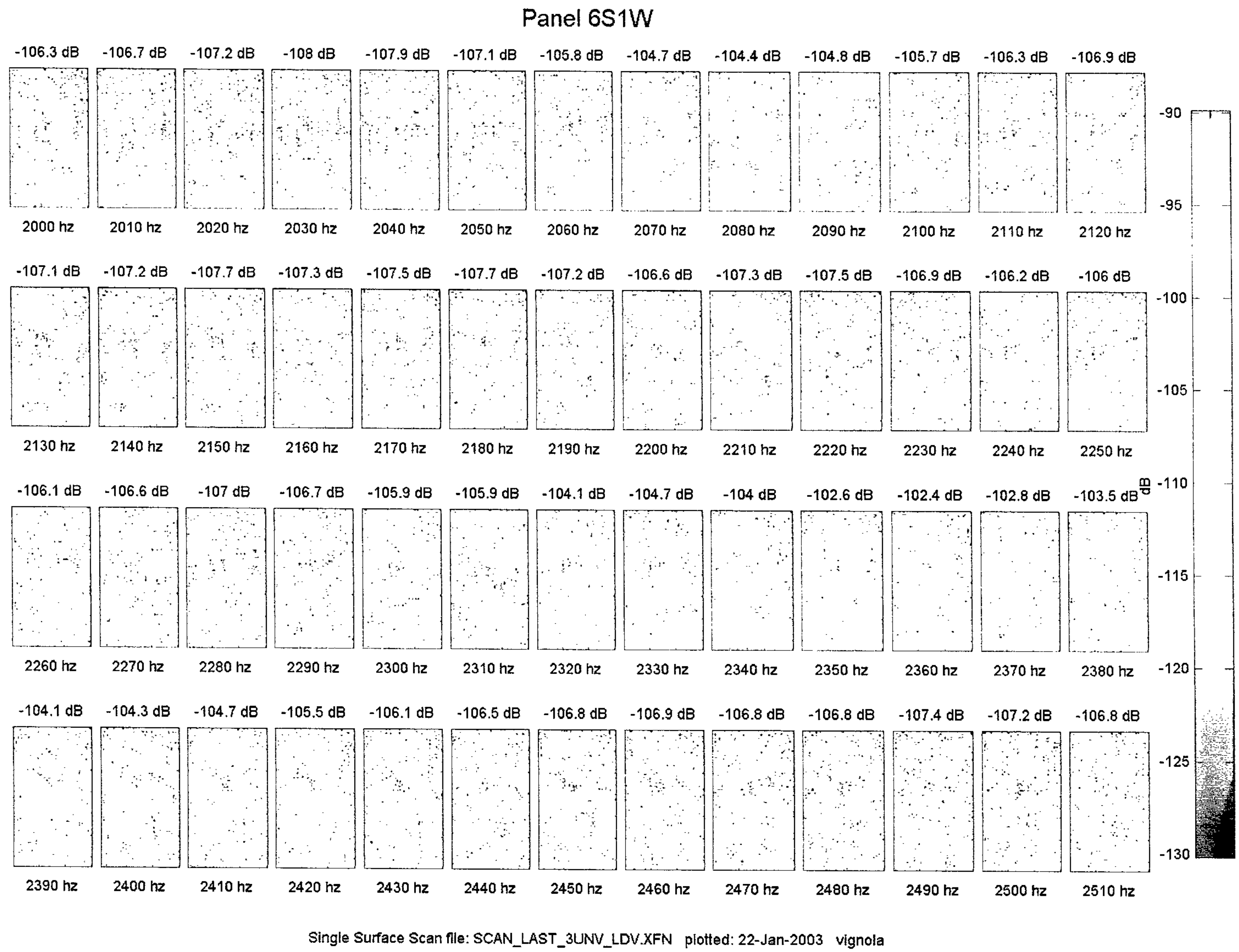
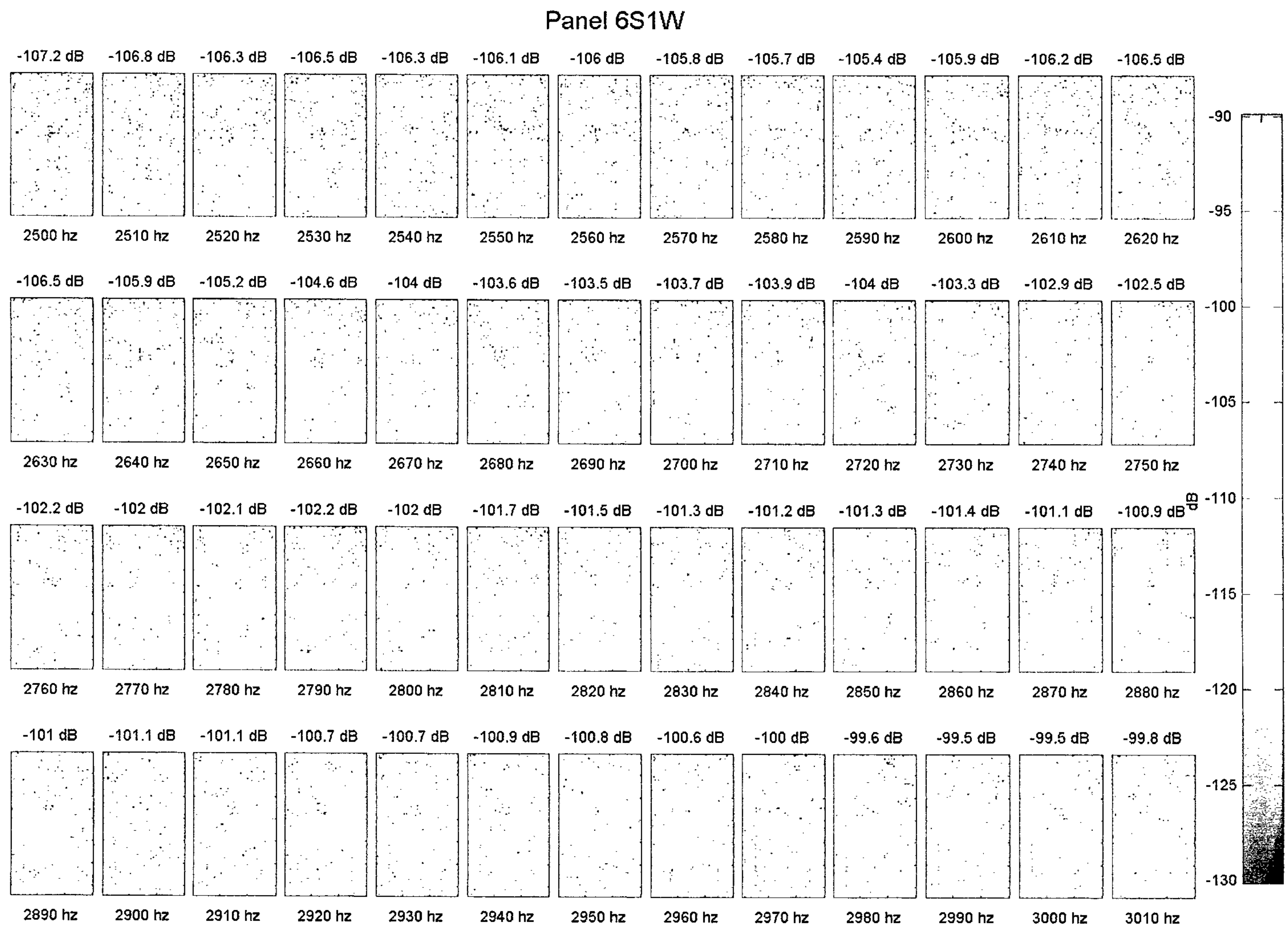

Panel 6S1W
-106.8 dB
1500 hz
-107.5 dB
1510 hz
-107.7 dB
1520 hz
-107.4 dB
1530 hz
-107.5 dB
1540 hz
-107.4 dB
1550 hz
-107.7 dB
1560 hz
-107.7 dB
1570 hz
-107.3 dB
1580 hz
-107.9 dB
1590 hz
-108.1 dB
1600 hz
-108.2 dB
1610 hz
-107.7 dB
1620 hz
-107.5 dB
1630 hz
-107.5 dB
1640 hz
-107.3 dB
1650 hz
-107.1 dB
1660 hz
-106.7 dB
1670 hz
-106.9 dB
1680 hz
-106.5 dB
1690 hz
-106.4 dB
1700 hz
-106.4 dB
1710 hz
-106.3 dB
1720 hz
-106.7 dB
1730 hz
-106.8 dB
1740 hz
-107.2 dB
1750 hz
-107 dB
1760 hz
-107.3 dB
1770 hz
-107.1 dB
1780 hz
-106.7 dB
1790 hz
-106.5 dB
1800 hz
-106.3 dB
1810 hz
-106.2 dB
1820 hz
-106.3 dB
1830 hz
-106.7 dB
1840 hz
-106.8 dB
1850 hz
-106.8 dB
1860 hz
-106.6 dB
1870 hz
-106.4 dB
1880 hz
-106.4 dB
1890 hz
-106.5 dB
1900 hz
-106.7 dB
1910 hz
-107 dB
1920 hz
-107.2 dB
1930 hz
-106.6 dB
1940 hz
-105.9 dB
1950 hz
-105.2 dB
1960 hz
-104.8 dB
1970 hz
-105.2 dB
1980 hz
-105.5 dB
1990 hz
-106.3 dB
2000 hz
-106.7 dB
2010 hz
-90
-95
-100
-105
-110 dB
-115
-120
-125
-130
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6p



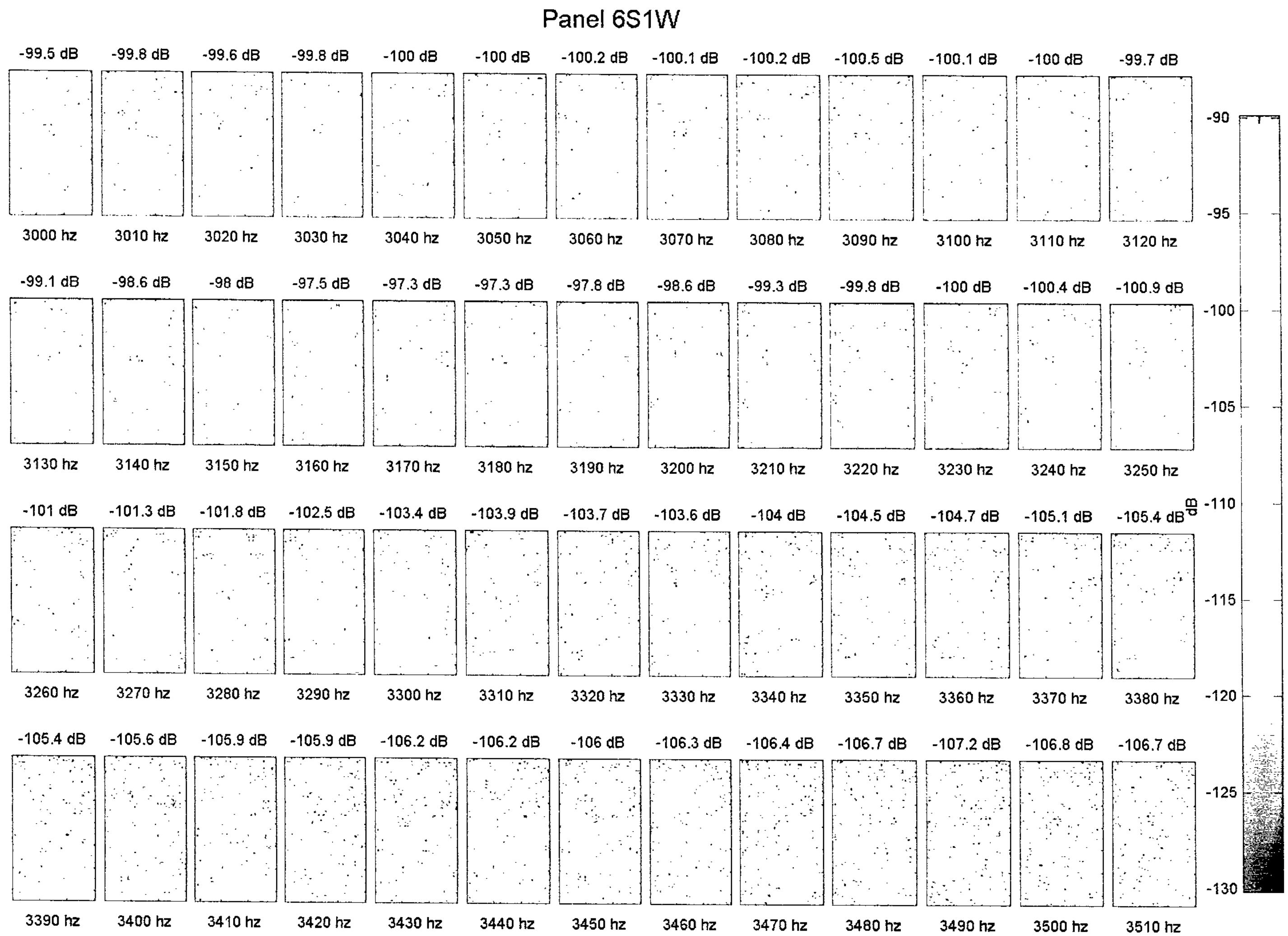
Panel 6S1W
-106.3 dB
-106.7 dB
-107.2 dB
-108 dB
-107.9 dB
-107.1 dB
-105.8 dB
-104.7 dB
-104.4 dB
-104.8 dB
-105.7 dB
-106.3 dB
-106.9 dB
2000 hz
2010 hz
2020 hz
2030 hz
2040 hz
2050 hz
2060 hz
2070 hz
2080 hz
2090 hz
2100 hz
2110 hz
2120 hz
-107.1 dB
-107.2 dB
-107.7 dB
-107.3 dB
-107.5 dB
-107.7 dB
-107.2 dB
-106.6 dB
-107.3 dB
-107.5 dB
-106.9 dB
-106.2 dB
-106 dB
2130 hz
2140 hz
2150 hz
2160 hz
2170 hz
2180 hz
2190 hz
2200 hz
2210 hz
2220 hz
2230 hz
2240 hz
2250 hz
-106.1 dB
-106.6 dB
-107 dB
-106.7 dB
-105.9 dB
-105.9 dB
-104.1 dB
-104.7 dB
-104 dB
-102.6 dB
-102.4 dB
-102.8 dB
-103.5 dB
2260 hz
2270 hz
2280 hz
2290 hz
2300 hz
2310 hz
2320 hz
2330 hz
2340 hz
2350 hz
2360 hz
2370 hz
2380 hz
-104.1 dB
-104.3 dB
-104.7 dB
-105.5 dB
-106.1 dB
-106.5 dB
-106.8 dB
-106.9 dB
-106.8 dB
-106.8 dB
-107.4 dB
-107.2 dB
-106.8 dB
2390 hz
2400 hz
2410 hz
2420 hz
2430 hz
2440 hz
2450 hz
2460 hz
2470 hz
2480 hz
2490 hz
2500 hz
2510 hz
-90
-95
-100
-105
-110
-115
-120
-125
-130
dB
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6q



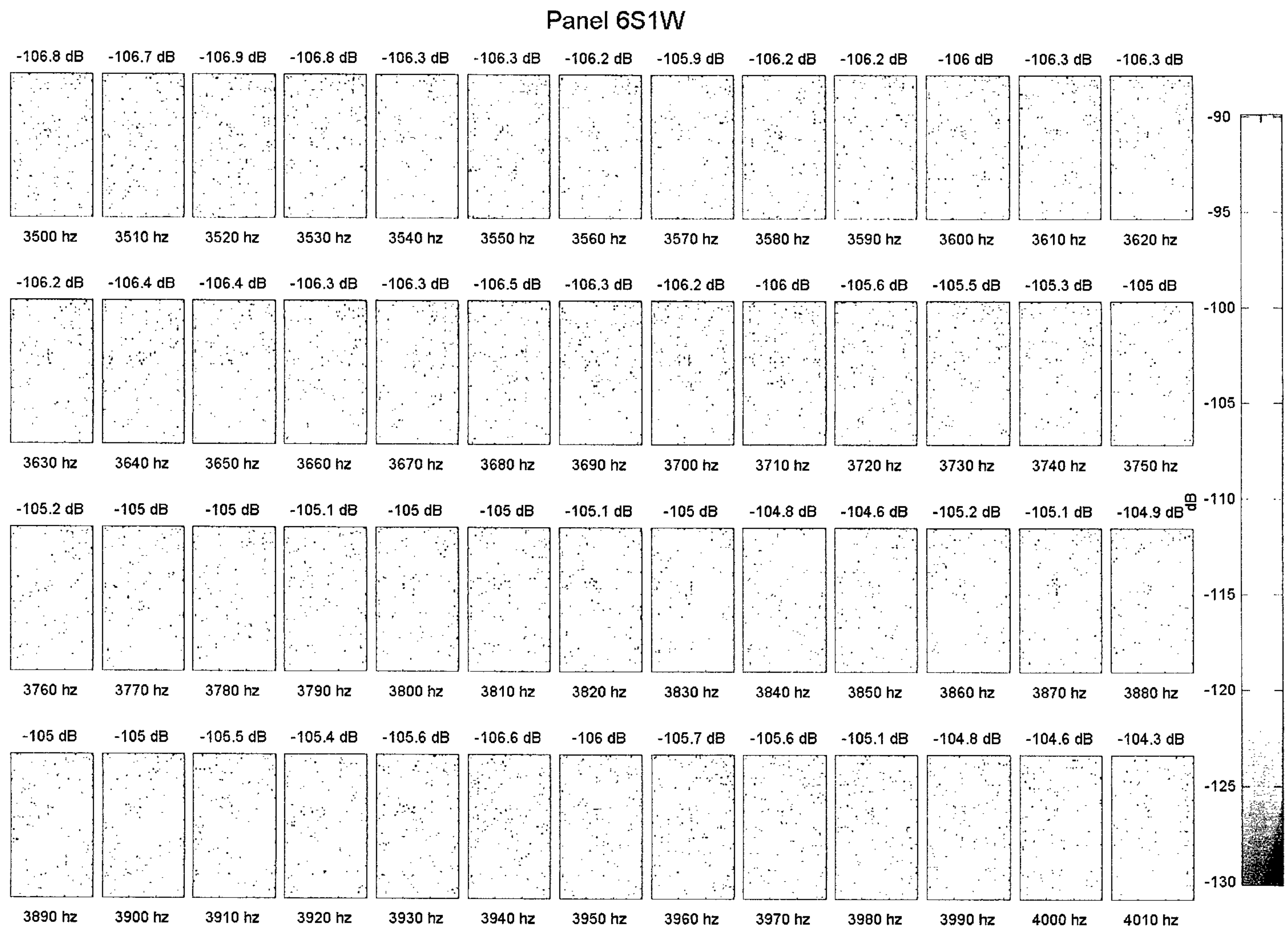
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6r



Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6s



Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6t

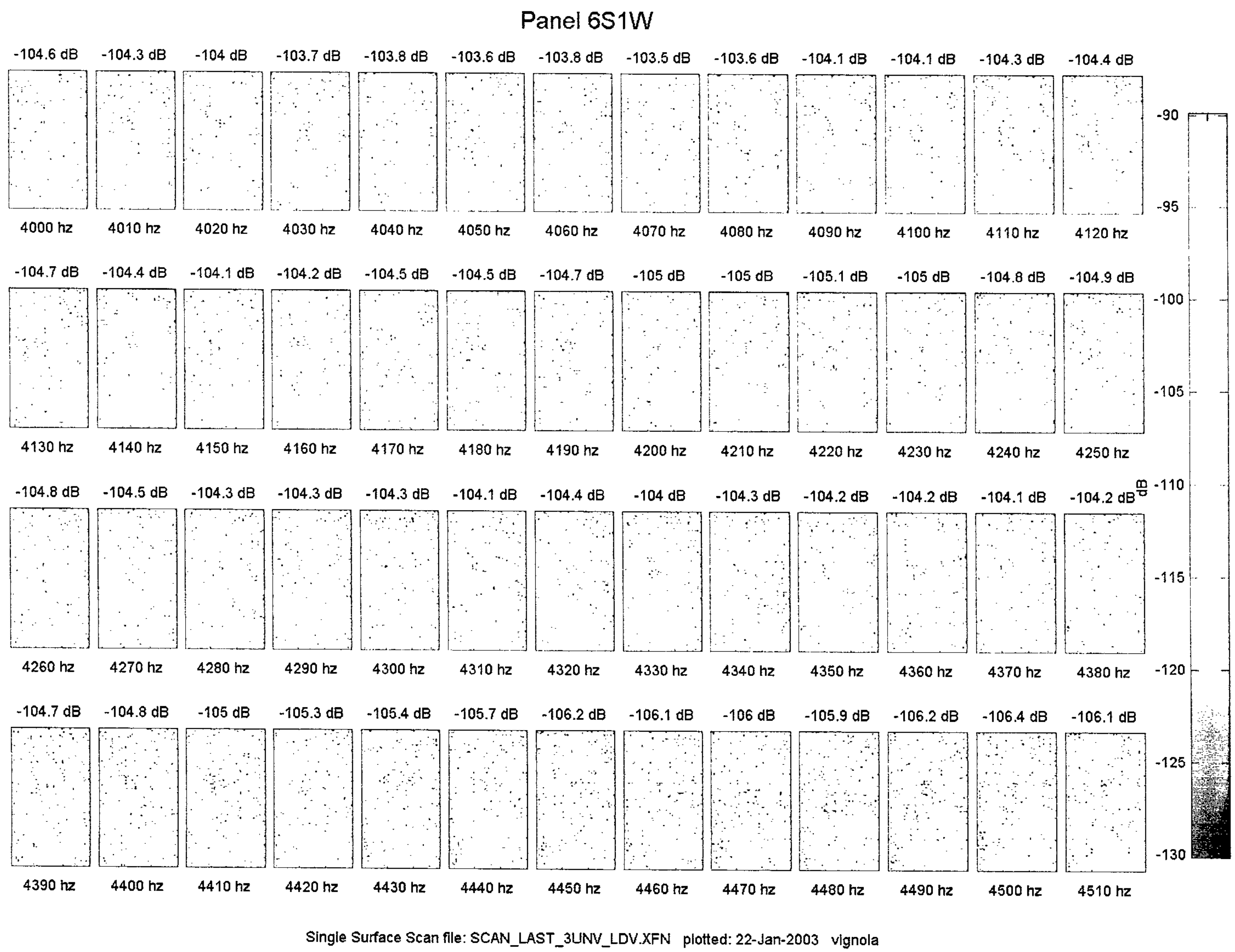
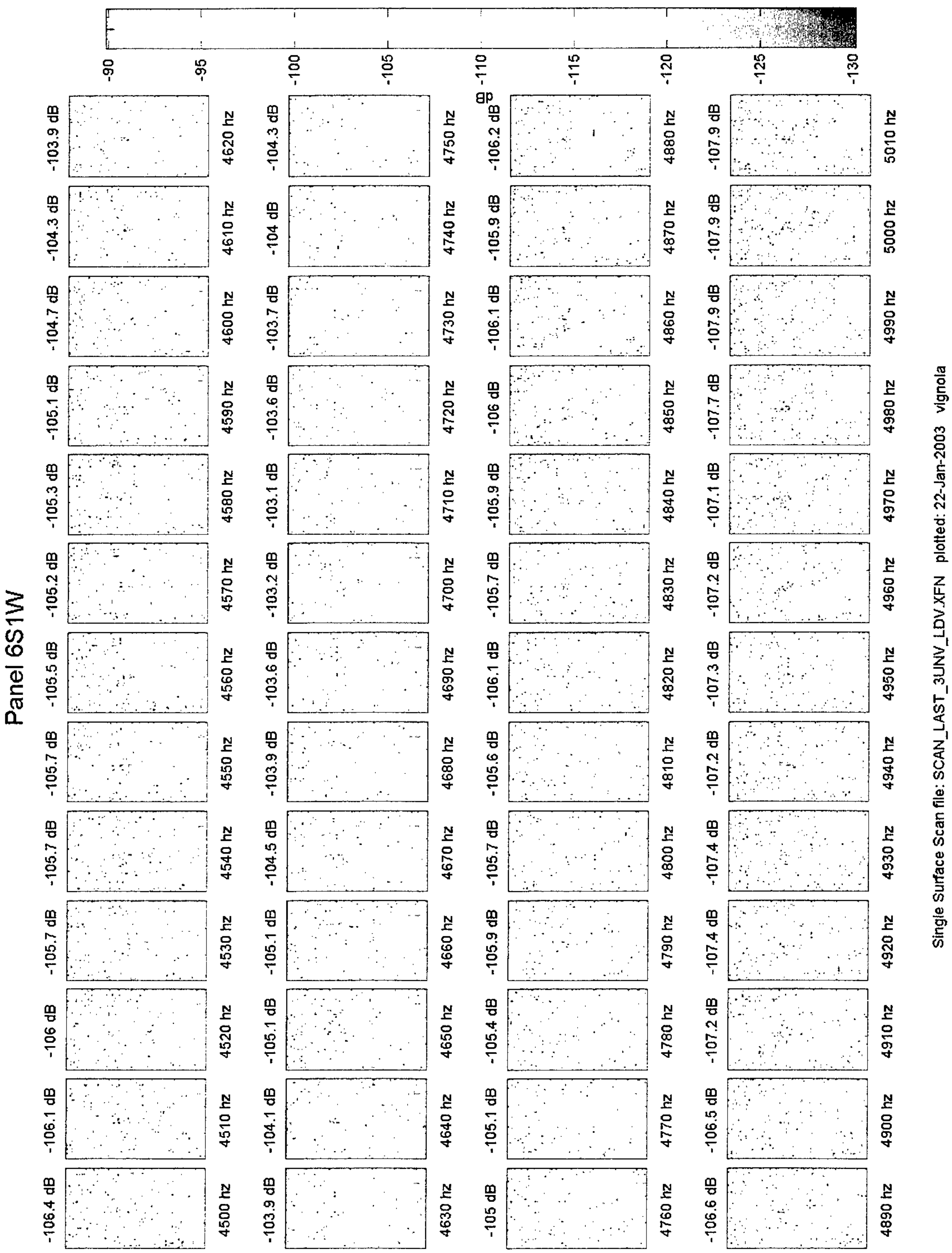

Panel 6S1W
-104.6 dB -104.3 dB -104 dB -103.7 dB -103.8 dB -103.6 dB -103.8 dB -103.5 dB -103.6 dB -104.1 dB -104.1 dB -104.3 dB -104.4 dB
4000 hz 4010 hz 4020 hz 4030 hz 4040 hz 4050 hz 4060 hz 4070 hz 4080 hz 4090 hz 4100 hz 4110 hz 4120 hz
-104.7 dB -104.4 dB -104.1 dB -104.2 dB -104.5 dB -104.5 dB -104.7 dB -105 dB -105 dB -105.1 dB -105 dB -104.8 dB -104.9 dB
4130 hz 4140 hz 4150 hz 4160 hz 4170 hz 4180 hz 4190 hz 4200 hz 4210 hz 4220 hz 4230 hz 4240 hz 4250 hz
-104.8 dB -104.5 dB -104.3 dB -104.3 dB -104.3 dB -104.1 dB -104.4 dB -104 dB -104.3 dB -104.2 dB -104.2 dB -104.1 dB -104.2 dB
4260 hz 4270 hz 4280 hz 4290 hz 4300 hz 4310 hz 4320 hz 4330 hz 4340 hz 4350 hz 4360 hz 4370 hz 4380 hz
-104.7 dB -104.8 dB -105 dB -105.3 dB -105.4 dB -105.7 dB -106.2 dB -106.1 dB -106 dB -105.9 dB -106.2 dB -106.4 dB -106.1 dB
4390 hz 4400 hz 4410 hz 4420 hz 4430 hz 4440 hz 4450 hz 4460 hz 4470 hz 4480 hz 4490 hz 4500 hz 4510 hz
dB
-90
-95
-100
-105
-110
-115
-120
-125
-130
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6u



Panel 6S1W
-106.4 dB
4500 hz
-106.1 dB
4510 hz
-106 dB
4520 hz
-105.7 dB
4530 hz
-105.7 dB
4540 hz
-105.7 dB
4550 hz
-105.5 dB
4560 hz
-105.2 dB
4570 hz
-105.3 dB
4580 hz
-105.1 dB
4590 hz
-104.7 dB
4600 hz
-104.3 dB
4610 hz
-103.9 dB
4620 hz
-103.9 dB
4630 hz
-104.1 dB
4640 hz
-105.1 dB
4650 hz
-105.1 dB
4660 hz
-104.5 dB
4670 hz
-103.9 dB
4680 hz
-103.6 dB
4690 hz
-103.2 dB
4700 hz
-103.1 dB
4710 hz
-103.6 dB
4720 hz
-103.7 dB
4730 hz
-104 dB
4740 hz
-104.3 dB
4750 hz
-105 dB
4760 hz
-105.1 dB
4770 hz
-105.4 dB
4780 hz
-105.9 dB
4790 hz
-105.7 dB
4800 hz
-105.6 dB
4810 hz
-106.1 dB
4820 hz
-105.7 dB
4830 hz
-105.9 dB
4840 hz
-106 dB
4850 hz
-106.1 dB
4860 hz
-105.9 dB
4870 hz
-106.2 dB
4880 hz
-106.6 dB
4890 hz
-106.5 dB
4900 hz
-107.2 dB
4910 hz
-107.4 dB
4920 hz
-107.4 dB
4930 hz
-107.2 dB
4940 hz
-107.3 dB
4950 hz
-107.2 dB
4960 hz
-107.1 dB
4970 hz
-107.7 dB
4980 hz
-107.9 dB
4990 hz
-107.9 dB
5000 hz
-107.9 dB
5010 hz
-90
-95
-100
-105
-110
dB
-115
-120
-125
-130
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6v

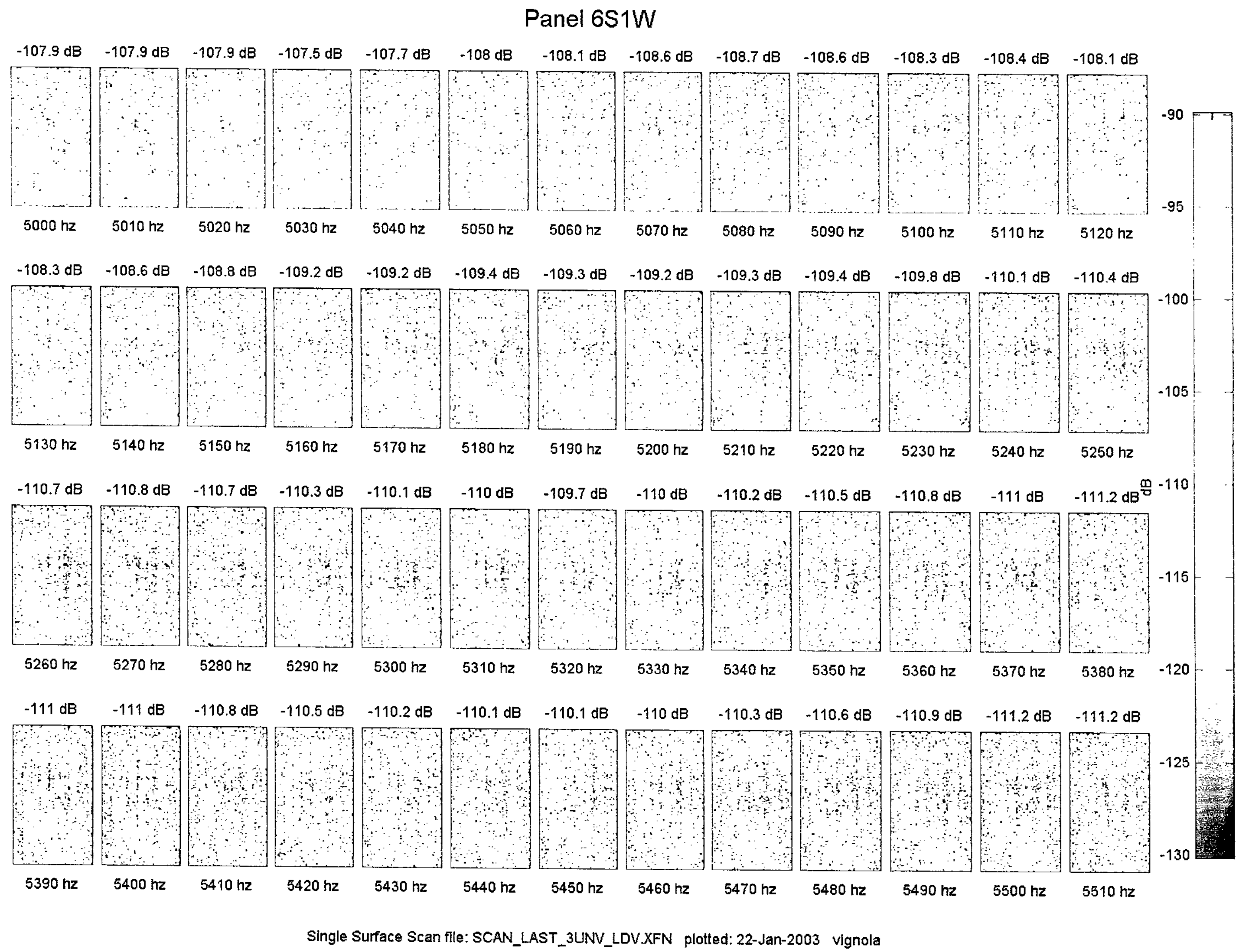

Panel 6S1W
-107.9 dB
5000 hz
-107.9 dB
5010 hz
-107.9 dB
5020 hz
-107.5 dB
5030 hz
-107.7 dB
5040 hz
-108 dB
5050 hz
-108.1 dB
5060 hz
-108.6 dB
5070 hz
-108.7 dB
5080 hz
-108.6 dB
5090 hz
-108.3 dB
5100 hz
-108.4 dB
5110 hz
-108.1 dB
5120 hz
-108.3 dB
5130 hz
-108.6 dB
5140 hz
-108.8 dB
5150 hz
-109.2 dB
5160 hz
-109.2 dB
5170 hz
-109.4 dB
5180 hz
-109.3 dB
5190 hz
-109.2 dB
5200 hz
-109.3 dB
5210 hz
-109.4 dB
5220 hz
-109.8 dB
5230 hz
-110.1 dB
5240 hz
-110.4 dB
5250 hz
-110.7 dB
5260 hz
-110.8 dB
5270 hz
-110.7 dB
5280 hz
-110.3 dB
5290 hz
-110.1 dB
5300 hz
-110 dB
5310 hz
-109.7 dB
5320 hz
-110 dB
5330 hz
-110.2 dB
5340 hz
-110.5 dB
5350 hz
-110.8 dB
5360 hz
-111 dB
5370 hz
-111.2 dB
5380 hz
-111 dB
5390 hz
-111 dB
5400 hz
-110.8 dB
5410 hz
-110.5 dB
5420 hz
-110.2 dB
5430 hz
-110.1 dB
5440 hz
-110.1 dB
5450 hz
-110 dB
5460 hz
-110.3 dB
5470 hz
-110.6 dB
5480 hz
-110.9 dB
5490 hz
-111.2 dB
5500 hz
-111.2 dB
5510 hz
-90
-95
-100
-105
-110
dB
-115
-120
-125
-130
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6w

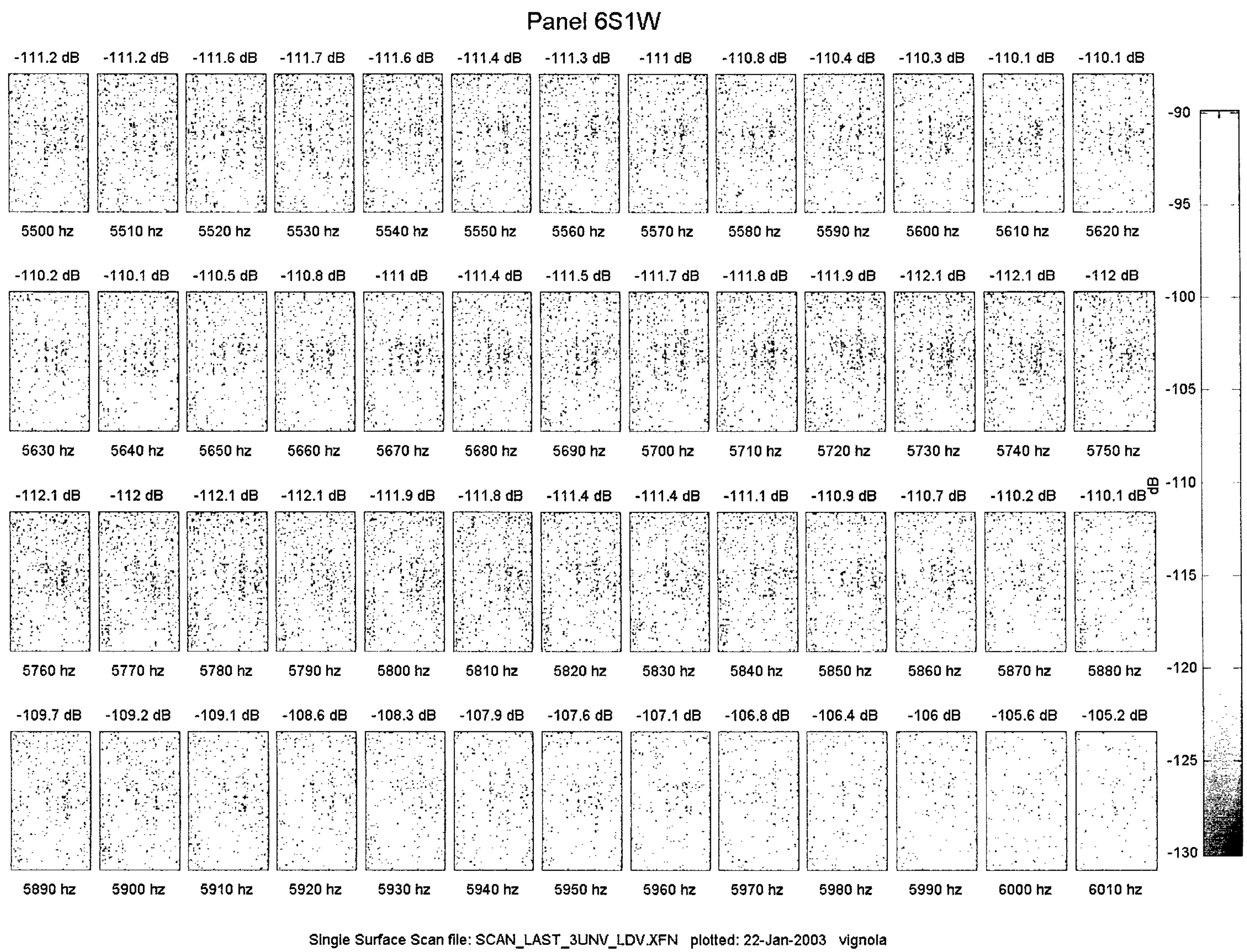

Panel 6S1W
-111.2 dB
5500 hz
-111.2 dB
5510 hz
-111.6 dB
5520 hz
-111.7 dB
5530 hz
-111.6 dB
5540 hz
-111.4 dB
5550 hz
-111.3 dB
5560 hz
-111 dB
5570 hz
-110.8 dB
5580 hz
-110.4 dB
5590 hz
-110.3 dB
5600 hz
-110.1 dB
5610 hz
-110.1 dB
5620 hz
-110.2 dB
5630 hz
-110.1 dB
5640 hz
-110.5 dB
5650 hz
-110.8 dB
5660 hz
-111 dB
5670 hz
-111.4 dB
5680 hz
-111.5 dB
5690 hz
-111.7 dB
5700 hz
-111.8 dB
5710 hz
-111.9 dB
5720 hz
-112.1 dB
5730 hz
-112.1 dB
5740 hz
-112 dB
5750 hz
-112.1 dB
5760 hz
-112 dB
5770 hz
-112.1 dB
5780 hz
-112.1 dB
5790 hz
-111.9 dB
5800 hz
-111.8 dB
5810 hz
-111.4 dB
5820 hz
-111.4 dB
5830 hz
-111.1 dB
5840 hz
-110.9 dB
5850 hz
-110.7 dB
5860 hz
-110.2 dB
5870 hz
-110.1 dB
5880 hz
-109.7 dB
5890 hz
-109.2 dB
5900 hz
-109.1 dB
5910 hz
-108.6 dB
5920 hz
-108.3 dB
5930 hz
-107.9 dB
5940 hz
-107.6 dB
5950 hz
-107.1 dB
5960 hz
-106.8 dB
5970 hz
-106.4 dB
5980 hz
-106 dB
5990 hz
-105.6 dB
6000 hz
-105.2 dB
6010 hz
-90
-95
-100
-105
-110
-115
-120
-125
-130
dB
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 6x

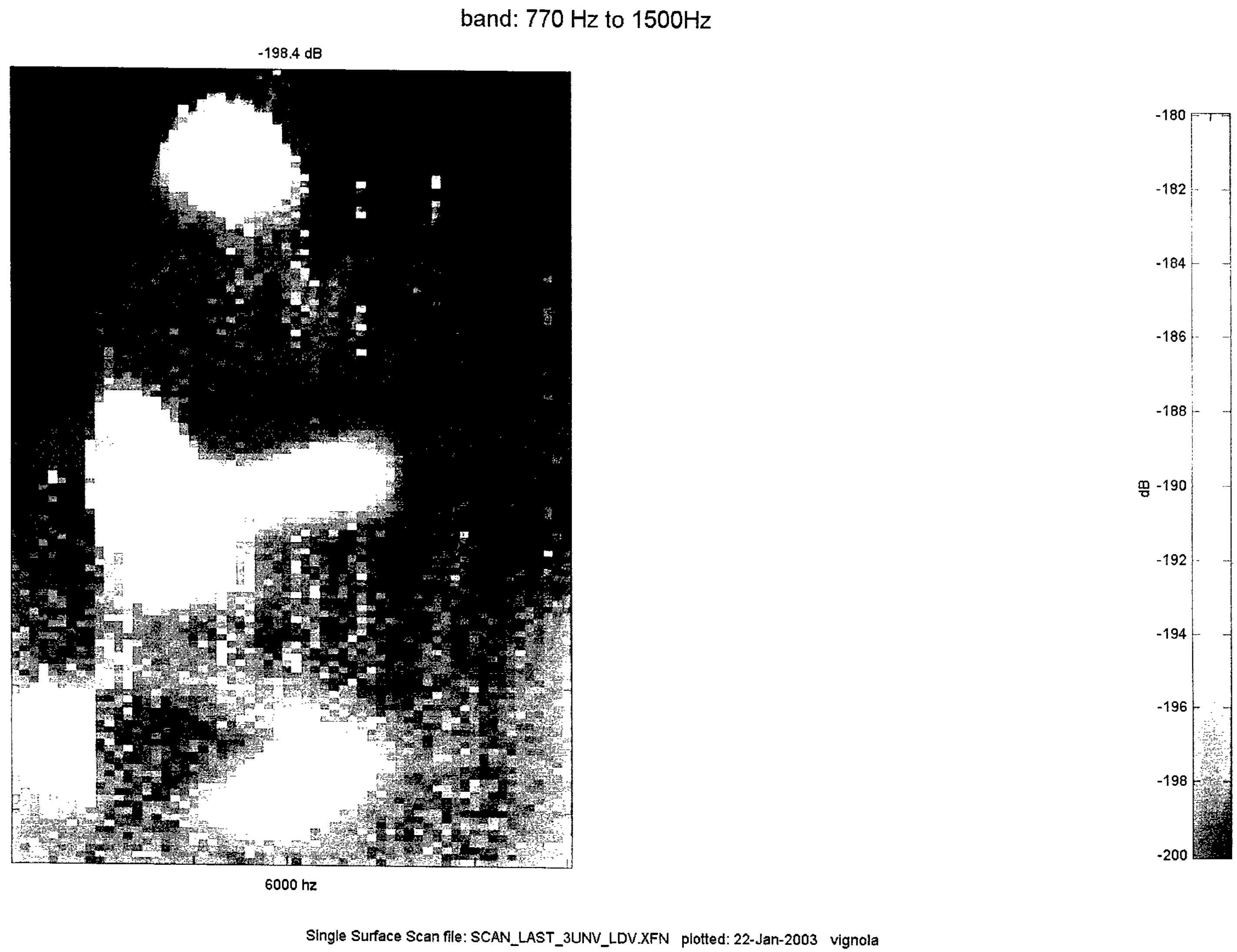
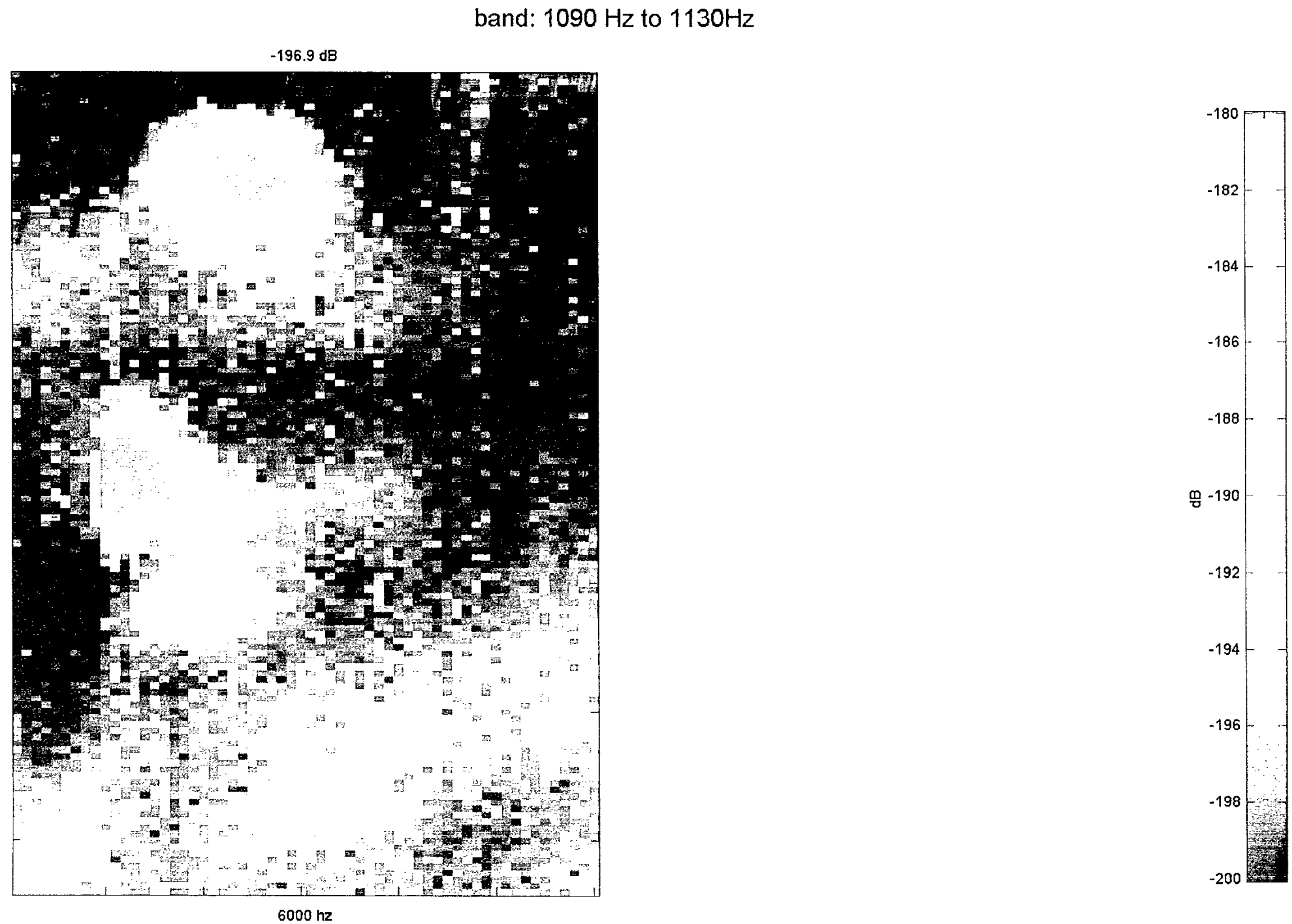

band: 770 Hz to 1500Hz
-198.4 dB
6000 hz
-180
-182
-184
-186
-188
-190
-192
-194
-196
-198
-200
dB
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 7a



Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 7b

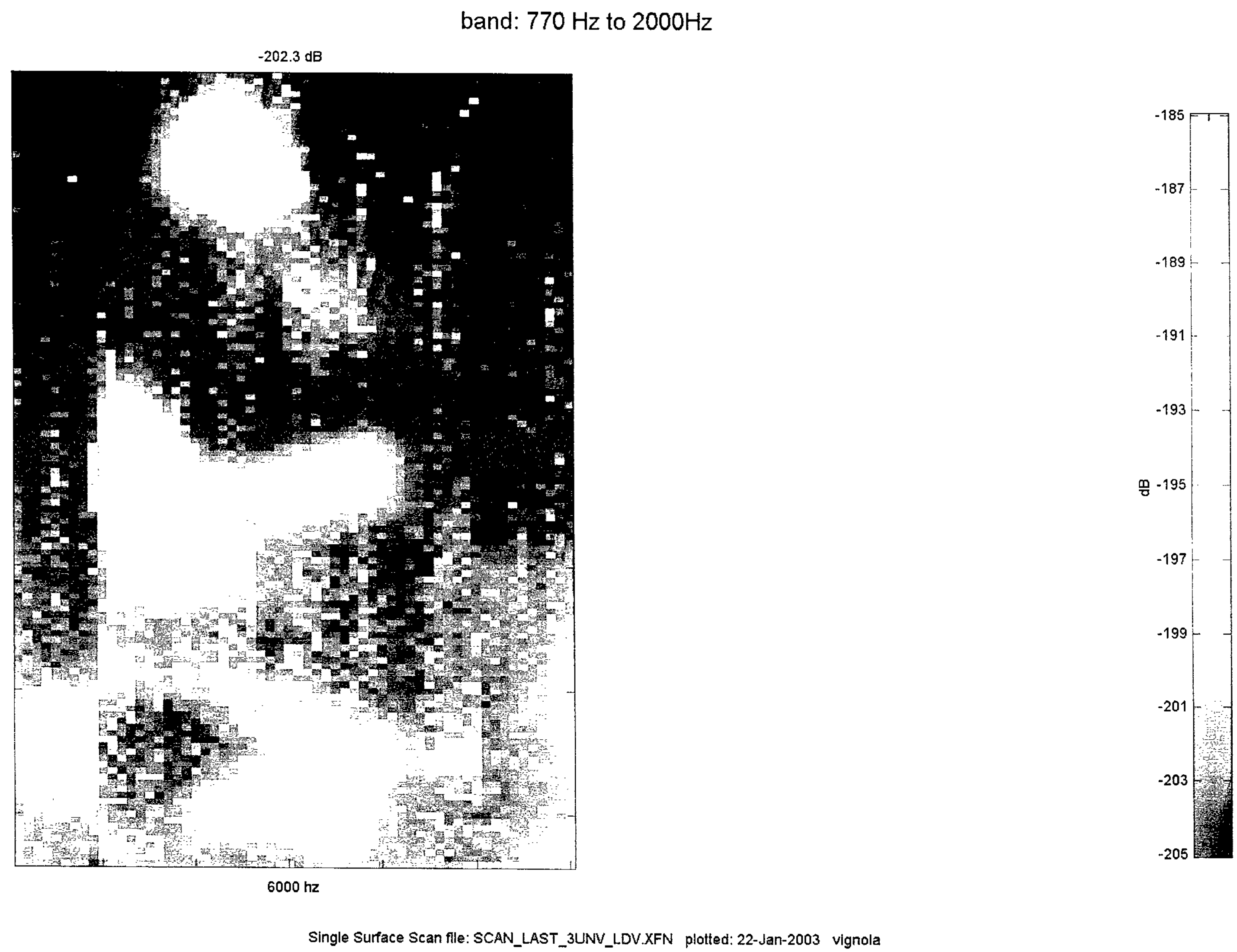
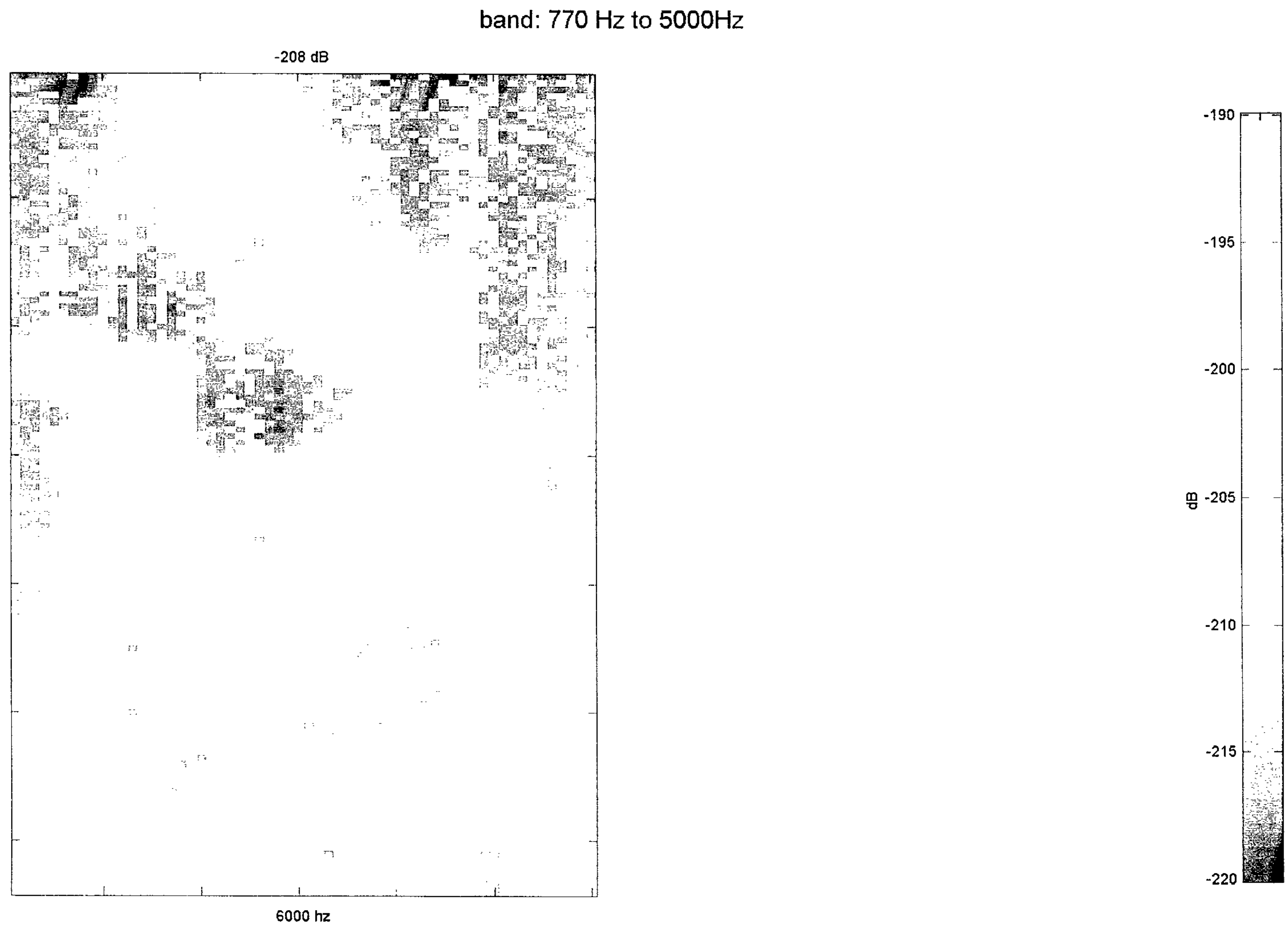

band: 770 Hz to 2000Hz
-202.3 dB
6000 hz
-185
-187
-189
-191
-193
-195
-197
-199
-201
-203
-205
dB
Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 7c



Single Surface Scan file: SCAN_LAST_3UNV_LDV.XFN plotted: 22-Jan-2003 vignola

Figure 8

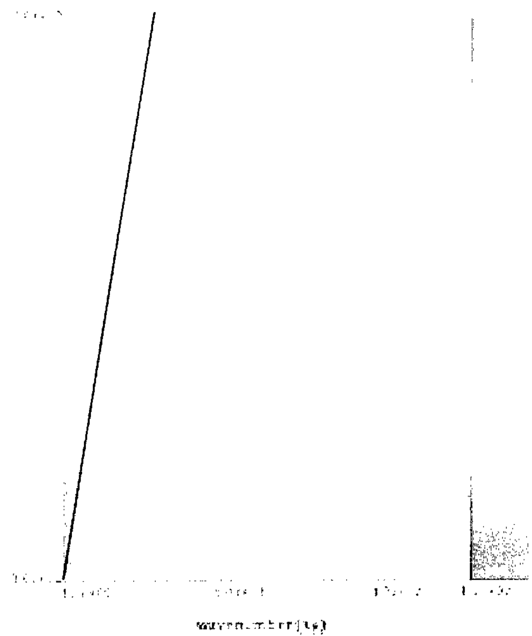


Figure 9 - Dispersion

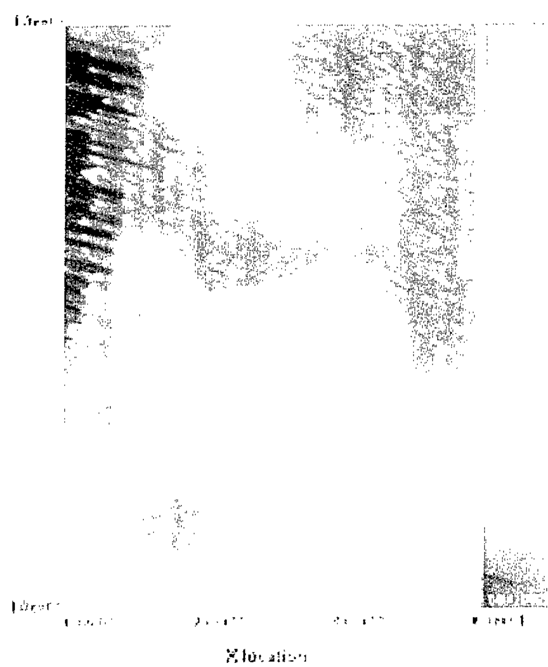


Figure 10 - Cross correlation, 770-1500 Hz

Figure 11 - Shear Wave Velocity^2, 980 Hz Inversion